Fisheries and Oceans Canada | Pêches et Océans Canada
Ecosystems and Oceans Science | Sciences des écosystèmes et des océans

Canadian Science Advisory Secretariat (CSAS)

Proceedings Series 2017/010

Maritimes Region

Proceedings of the Regional Framework Discussion on Stock Substructure of Northwest Atlantic Fisheries Organization (NAFO) Divisions 3NOPs4VWX5Zc Atlantic Halibut, *Hippoglossus hippoglossus* (Scotian Shelf and Southern Grand Banks)

March 9-11, 2016
Halifax, Nova Scotia

Chairperson: Martha Krohn
Editor: Kristian Curran

Bedford Institute of Oceanography
Fisheries and Oceans Canada
1 Challenger Drive, PO Box 1006
Dartmouth, Nova Scotia B2Y 4A2

July 2017

Canada

Foreword

The purpose of these Proceedings is to document the activities and key discussions of the meeting. The Proceedings may include research recommendations, uncertainties, and the rationale for decisions made during the meeting. Proceedings may also document when data, analyses or interpretations were reviewed and rejected on scientific grounds, including the reason(s) for rejection. As such, interpretations and opinions presented in this report individually may be factually incorrect or misleading, but are included to record as faithfully as possible what was considered at the meeting. No statements are to be taken as reflecting the conclusions of the meeting unless they are clearly identified as such. Moreover, further review may result in a change of conclusions where additional information was identified as relevant to the topics being considered, but not available in the timeframe of the meeting. In the rare case when there are formal dissenting views, these are also archived as Annexes to the Proceedings.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

© Her Majesty the Queen in Right of Canada, 2017
ISSN 1701-1280

Correct citation for this publication:

DFO. 2017. Proceedings of the Regional Framework Discussion on Stock Substructure of Northwest Atlantic Fisheries Organization (NAFO) Divisions 3NOPs4VWX5Zc Atlantic Halibut, *Hippoglossus hippoglossus* (Scotian Shelf and Southern Grand Banks); March 9-11, 2016. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2017/010.

TABLE OF CONTENTS

SUMMARY IV

SOMMAIRE V

INTRODUCTION 1

PRESENTATIONS 2

BIOLOGY AND HISTORY 2

Presentation: Current View of Stock Structure, How We Came to Question it, and Workshop Expectations 2

Presentation: History and Recovery of Atlantic Halibut: A Large, Long-lived, and Exploited Groundfish 3

Presentation: From the Other Coast: Pacific Halibut from California to the Bering Sea: Biology and Management Don't Mix 5

Presentation: Atlantic Industry Perspective: Who We Are and What We Have Learned from the Longline Survey 6

DISTRIBUTION AND MOVEMENT (TAGGING STUDIES) 7

Presentation: Recovery of the Gulf of St. Lawrence Atlantic Halibut Fishery to a 50-year High: Data Needs and Collaborative Research Opportunities 7

Presentation: Effects of Pop-up Satellite Archival Tag (PSAT) Temporal Data Resolution on Interpretations of Behaviour, Vertical Habitat Use and Movement 9

Presentation: Habitat Associations, Seasonal Movements, and Population Structure of Atlantic Halibut in the Gulf of St. Lawrence Inferred from Pop-up Satellite Archival Ttags (PSAT) 12

Presentation: USA Perspective and Pop-up Satellite Archival Tag (PSAT) Plans for Atlantic Halibut on Georges Banks and in the Gulf of Maine 16

Presentation: History of Tagging on the Scotian Shelf and Southern Grand Banks 17

STOCK STRUCTURE 19

Presentation: Changes in Juvenile Atlantic Halibut Distribution and Connectivity Through Decades of Fisheries Exploitation in the Northwest Atlantic 19

Presentation: Variation in Length at Maturity and Distribution of Spawning Fish in NAFO Divisions 3NOPs4VWX as Estimated from the Halibut Longline Survey 25

Presentation: Size at Age by NAFO Division 26

Presentation: Status of Atlantic Halibut in Canada Versus the United States 27

HIGH DENSITY AREAS 28

Presentation: Species Distribution Model - Northwest Atlantic Habitat Model and Plans: Adding Prey Availability and Fishery Closures as Predictors in the Atlantic Halibut Model 28

DISCUSSION 29

CONCLUSIONS 39

REFERENCES CITED 39

APPENDICES 42

APPENDIX 1: LIST OF MEETING PARTICIPANTS 42

APPENDIX 2: MEETING TERMS OF REFERENCE 43

APPENDIX 3: MEETING AGENDA 45

SUMMARY

Atlantic Halibut (*Hippoglossus hippoglossus*) is a large and long-lived flatfish. It ranges widely in the Northwest Atlantic. In Canada, Atlantic Halibut has been assessed as two regional-scale stocks since 1988, yet the knowledge about its basic ecology is limited. Population structure, migration routes, timing and location of spawning are all unknown. Currently, the management units are the Northwest Atlantic Fisheries Organization (NAFO) Divisions 3NOPs4VWX5Zc (Scotian Shelf and Southern Grand Banks) and NAFO Divisions 4RTS (Gulf of St, Lawrence). The management units were defined by tagging data that showed some Halibut travelled long distances but that mixing between these two areas was low. Recent research investigated Halibut that span the border separating the United States of America (US) and Canada and showed that, from 1965 to 2014, juvenile abundance was, on average, five times greater on the Canadian side of the Hague Line (the nautical international border between US and Canadian waters).

The median per cent of occupied sets on the Canadian side was about 4 times greater than in US waters 2.5%), despite the availability of "suitable" habitat on the US side. There was also evidence to suggest that Atlantic Halibut in US and Canadian waters are connected through the Bay of Fundy and eastern Gulf of Maine. The available evidence suggested that Halibut have not re-established in the US after historical overfishing and that Halibut exhibit a finer spatial structure than assumed in the stock assessment. Subsequent research has identified high density areas of juvenile Halibut that may be indicative of 3NOPs4VWX5Zc Atlantic Halibut stock substructure on the Scotian Shelf and Southern Grand Banks. A better understanding of Halibut substructure and connectivity between high density areas could provide an improved basis for sustainable management. Multiple lines of evidence are necessary to evaluate stock structure and the appropriate management strategies in the face of this new data synthesis.

Recovery of the stock has allowed for increased access by Canadian domestic and international fishing fleets. Continued sustainable exploitation of this resource would benefit from a collaborative approach between the three coastal states that have a primary interest in the stock: Canada; US; and France. As part of the Regional Peer Review process, a meeting was held on March 9-11, 2016, at the Delta Barrington Hotel in Halifax, Nova Scotia, to review a science framework that could be used to support development of a Halibut research program and a common understanding of stock structure among the three coastal states. The discussion was guided by a series of presentations. This Proceedings document constitutes a record of meeting discussions, recommendations, and conclusions, and any statements within should not be attributed as being consensus-based. A Science Advisory Report was not a product of the meeting.

Comptes rendus des discussions dans le cadre régional sur la sous-structure du stock de flétan de l'Atlantique, *Hippoglossus hippoglossus*, des divisions 3NOPs4VWX5Zc de l'Organisation des pêches de l'Atlantique nord-ouest (OPANO) [plateau néo-écossais et sud des Grands Bancs]

SOMMAIRE

Le flétan de l'Atlantique (*Hippoglossus hippoglossus*) est un gros poisson plat de grande longévité. Il est bien présent dans l'Atlantique Nord-Ouest Au Canada, le flétan de l'Atlantique est évalué selon deux stocks à échelle régionale depuis 1988, mais les connaissances sur son écologie de base sont limitées. La structure de la population, les voies de migration, les périodes et les sites de frai sont inconnus. Actuellement, les unités de gestion sont les divisions 3NOPs4VWX5Zc (plateau néo-écossais et du sud des Grands Bancs) et les divisions de l'OPANO 4RTS (golfe du Saint-Laurent) de l'OPANO. Les unités de gestion ont été définies par les données de marquage qui ont démontré que certains flétans parcouraient de longues distances, mais que l'interaction entre ces deux zones était faible. De récentes recherches ont été menées sur les flétans qui s'étendent de la frontière séparant les États-Unis d'Amérique et le Canada et ont démontré que de 1965 à 2014 l'abondance des jeunes poissons était, en moyenne, 5 fois plus élevée du côté canadien de la ligne de démarcation de la Haye (la frontière nautique internationale entre les eaux américaines et canadiennes).

Le pourcentage médian d'occupation du côté canadien était environ 4 fois plus élevé que celui des eaux américaines (2,5 %) malgré la disponibilité d'habitat « convenable » du côté américain. Des preuves suggèrent également que les flétans de l'Atlantique dans les eaux américaines et canadiennes sont reliés par la baie de Fundy et l'est du golfe du Maine. Les preuves disponibles suggèrent que le flétan ne s'est pas rétabli aux États-Unis après la surpêche historique et, au moment de l'évaluation du stock, il présentait une structure spatiale plus fine que prévu. Des études récentes ont déterminé des secteurs ayant une densité élevée de jeunes flétans qui pourraient être le signe d'une sous-structure du stock de flétan des divisions 3NOPs4VWX5Zc sur le plateau néo-écossais et dans le sud des Grands Bancs. Une meilleure compréhension de la sous-structure des flétans et de la connectivité entre les secteurs ayant une densité élevée pourrait fournir une base améliorée pour une gestion durable. De nombreuses sources de données sont nécessaires pour évaluer la structure du stock et les stratégies de gestion appropriées compte tenu de cette nouvelle synthèse des données.

Le rétablissement du stock a permis d'augmenter l'accès des flottilles de pêche canadiennes et internationales. L'exploitation durable continue de cette ressource tirerait profit d'une approche concertée entre les trois états côtiers qui ont une première responsabilité pour le stock, à savoir le Canada, les États-Unis et la France. Dans le cadre du processus d'examen régional par les pairs, une rencontre a eu lieu du 9 au 11 mars 2016, à l'hôtel Delta Barrington à Halifax, en Nouvelle-Écosse, pour procéder à un examen du cadre scientifique qui pourrait être utilisé pour soutenir l'élaboration d'un programme de recherche sur le flétan et une compréhension commune de la structure du stock entre les trois États côtiers. La discussion était appuyée par une série de présentations. Le présent document est un compte rendu des discussions de la rencontre, des recommandations et des conclusions. Les énoncés s'y trouvant ne devraient pas être considérés comme fondés sur le consensus. Aucun avis scientifique n'a été produit pendant la réunion.

INTRODUCTION

Atlantic Halibut (*Hippoglossus hippoglossus*) is a large and long-lived flatfish. It ranges widely in in Northwest Atlantic. In Canada, Atlantic Halibut has been assessed as two regional-scale stocks since 1988, yet our knowledge about its basic ecology is limited. Population structure, migration routes, timing and location of spawning are all unknown. Currently, the management units are the Northwest Atlantic Fisheries Organization (NAFO) Divisions 3NOPs4VWX5Zc (Scotian Shelf and Southern Grand Banks) and NAFO Divisions 4RTS (Gulf of St. Lawrence). The management units were reasonably defined by tagging data that showed some Halibut travelled long distances but that mixing between the two basic units was low. Recent research investigated Halibut that span the border separating the United States of America (US) and Canada and showed that, from 1965 to 2014, juvenile abundance was, on average, five times greater on the Canadian side of the Hague Line (the nautical international border between Canada and US) (Shackell et al., 2016). The median per cent of occupied sets in Canadian waters was about four times greater than in US waters (2.5%), despite the availability of "suitable" habitat in the US. There was also evidence to suggest that Atlantic Halibut in US and Canadian waters are connected through the Bay of Fundy and eastern Gulf of Maine.

Combined with historical studies and results of tagging data, the results suggested that Halibut have not re-established in the US due to historical overfishing and that Halibut exhibit a finer spatial structure than assumed in the Canadian stock assessment. Subsequent research has identified high density areas of juvenile Halibut that may be indicative of 3NOPs4VWX5Zc Atlantic Halibut stock substructure on the Scotian Shelf and Southern Grand Banks. Recovery of the stock has allowed for increased access by Canadian domestic and international fishing fleets. Continued sustainable exploitation of this resource would benefit from a collaborative approach between the three coastal states that have a primary interest in the stock: Canada; United States; and France. A better understanding of Halibut substructure and connectivity between high density areas could provide an improved basis for sustainable management. Multiple lines of evidence are necessary to evaluate stock structure and the appropriate management strategies in the face of this new data synthesis. A new assessment framework for 3NOPs4VWX5Zc Atlantic Halibut was accepted in November 2014 (DFO 2015a). The last stock assessment was conducted December 8-9, 2014 (DFO 2015b) and a stock update was completed December 3, 2015. The 3NOPs4VWX5Zc Atlantic Halibut stock is considered to be in the healthy zone. Recent research and these Proceedings are an effort to improve our understanding of the stock before the next review of the assessment framework (approximately 2019).

As part of the Regional Peer Review process, a meeting was held on March 9-11, 2016, at the Delta Barrington Hotel in Halifax, Nova Scotia, to review a science framework that could be used to support development of a Halibut research program and a common understanding of stock structure among the three coastal states. The meeting Chairperson, Martha Krohn, introduced herself, followed by an introduction of meeting participants (Appendix 1). The Chair then invited participants to review the meeting Terms of Reference (Appendix 2) and Agenda (Appendix 3). The discussion was guided by a series of presentations. This Proceedings document constitutes a record of meeting discussions, recommendations, and conclusions, and any statements within should not be attributed as being consensus-based. A Science Advisory Report was not a product of the meeting.

PRESENTATIONS

BIOLOGY AND HISTORY

Presentation: Current View of Stock Structure, How We Came to Question it, and Workshop Expectations

Science Lead: N. Shackell
Rapporteur: K. Curran

Summary

Atlantic Halibut have resurged in the Northwest Atlantic since the mid-2000s, yet the knowledge about its basic ecology is limited. Neither population structure, migration routes, or where and when the fish spawn are fully understood. Atlantic Halibut are now the most commercially-valuable groundfish in DFO's Maritimes Region, and interest is growing. There is opportunity to learn from Northwest Atlantic groundfish fishery collapses in the early-1990s and incorporate that knowledge into the next round of the Halibut stock assessment framework (approximately 2019). Two related themes that emerge from the literature are relevant here:

1. the spatial scale of a stock management unit is often larger than the spatial scale of genetic and/or life history differences among potential subpopulations (Bradbury et al. 2008, Cadrin et al. 2013, Cadrin et al. 2010, Kuparinen et al. 2016, Roney et al. 2016, Smedbol and Wroblewski 2002), and
2. even in the absence of genetic/life history differences, the spatial distribution of fish and fishing is never uniform across a region, and local concentrations can be fished out (spatial erosion (Ames and Lichter 2013, Bartolino et al. 2012, Ciannelli et al. 2013, Frank and Brickman 2000, Kerr et al. 2010, Maury and Gascuel 2001, and Shackell et al. 2005)).

Given the evidence in other species/systems, it is possible to address whether there is spatial variation in demographic rates in Halibut, and whether there is a need to safeguard against spatial erosion by an appropriate spatial allocation of fishing effort.

The current view of Halibut stock structure is that one population ranges from the southern Grand Banks to Gulf of Maine area. The information used in the stock assessment assumes a constant growth rate and size at maturity, etc. On the other hand, the allocation of fishing effort is done at a smaller scale and corresponds roughly to NAFO divisions. Adults are hypothesized to spawn off of southern Grand Banks, their larvae drift to southwest Nova Scotia, where they grow, and they eventually migrate back to Newfoundland as they mature. This hypothesis was just an idea as only two larvae have ever been found in the wild in this area and knowledge of spawning locations is very poor. Our objectives for this workshop were to review ecological/demographic information on Halibut throughout the Northwest Atlantic and to set research goals that would inform the next framework assessment.

Discussion

A participant inquired if it was believed genetic variation or alleles were being lost from the stock, as a loss of alleles is unrecoverable. The Science Lead responded that this was unknown, but a question that could be explored from a research perspective. Another participant asked if there are archived genetic samples of Atlantic Halibut in the region, and the Science Lead noted that that otoliths do exist but the type of genetic studies being proposed could not be undertaken as the otoliths have no associated tissue that is needed. It was noted that the Groundfish Enterprise Allocation Council (GEAC) is looking into the plausibility of genetic studies using the endolymph obtained within the otolith for Atlantic Cod. Last, it was

noted that the Huntsman Marine Science Centre may have stored Atlantic Halibut tissue samples that could be used, as might the Canadian Museum of Nature.

Presentation: History and Recovery of Atlantic Halibut: A Large, Long-lived, and Exploited Groundfish

Science Lead: N. den Heyer
Rapporteur: K. Curran

Summary

Atlantic Halibut (*Hippoglossus hippoglossus*) is a large, long-lived, sexually dimorphic flatfish. Female Atlantic Halibut are assumed to reach 50% maturity at about 120 cm, while males are assumed to reach 50% maturity at about 80 cm (see Shackell, these proceedings for review). The management unit definition (3NOPs4VWX5Zc) is based largely on tagging results that indicated that some Atlantic Halibut can move extensively throughout the Canadian North Atlantic. Prior to 1988, the Atlantic Halibut fishery was unregulated, at which time a Total Allowable Catch (TAC) was implemented. In 1994, a minimum legal size limit of 81 cm was established. At the beginning of the 18th Century, Halibut were a nuisance bycatch of the cod fishery (Grasso 2008). In the mid-1800s a Halibut fishery developed in New England. The New England Halibut fleet initially concentrated on shallow water near Cape Cod, but subsequently expanded to deep waters in the Gulf of Maine, and then north along the Atlantic coast of Nova Scotia, Newfoundland and in the Gulf of St. Lawrence. By the late 1800s, the Atlantic Halibut fishery had collapsed. Landings from the Scotian Shelf and Gulf of St. Lawrence increased slowly until the mid-1900s. By 1970, when the recent assessment models begin, landings had already begun to decline throughout Canadian waters. In the last 40 years, the Atlantic Halibut fishery on the Scotian Shelf and southern Grand Banks has changed. Early in the time series, as much as 50% of landings by weight came from otter trawl gear, but since 1993 the Atlantic Halibut landings are primarily associated with longlining.

The DFO Research Vessel (RV) survey provides an index of abundance for Atlantic Halibut primarily between 30 and 70 cm total length; as a result, estimates of exploitable (≥81 cm) biomass from the RV survey are considered unreliable. In 1998, two inshore fishing associations and DFO began a longline Halibut survey on the Scotian Shelf and southern Grand Banks. This survey is now completed in collaboration with those groups and the Atlantic Halibut Council (AHC). The AHC supports a variety of research programs, including the aging completed in 2007 and the Halibut All Sizes Tagging (HAST) program that started in 2006. A multi-year mark-recapture analysis of the tagging data provides estimates of natural and fishing mortality. Using the age-length keys generated from the aging program, the first length-based, age-structured stock assessment model for this stock was fit to data from 1970 to 2009. This population model showed that the total stock biomass had been increasing since the mid-1990s (Trzcinski et al. 2011, Trzcinski and Bowen 2016). A new statistical-catch-length/age assessment model fit to data from 1970 to 2013 (Cox et al. 2016) shows that the recovery has continued, with both the spawning stock biomass and the total biomass the highest since 1970 (Figure 1).

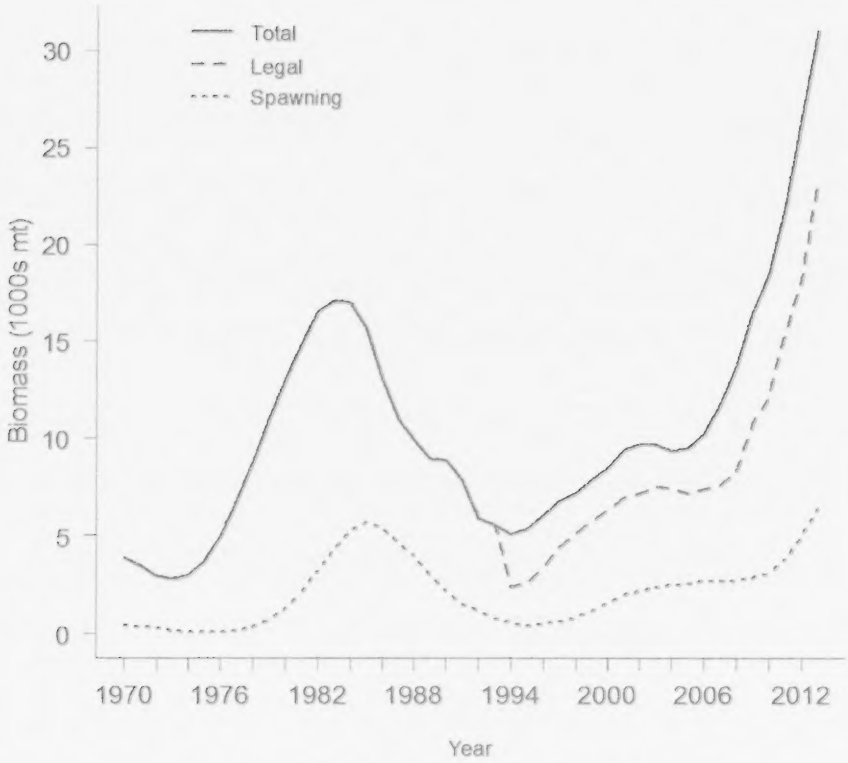

Figure 1. Estimated biomass of Atlantic Halibut on the Scotian Shelf and southern Grand Banks since 1970 (Cox et al. 2016). The solid line is total biomass, the long dashes is the legal (>81 cm) biomass and the dashed line is spawning stock biomass.

Trzcinski and Bowen (2016) conclude that the recovery of Halibut was a result of high recruitment and good management including low TACs, the introduction of minimum size and the closure of the cod fishery, and the reduction in bycatch associated with that fishery. The analysis of F and B ratios since 1970 indicated good periods where F was less than F_{msy} and the B was greater than B_{msy}, cautionary times where either F was greater than F_{msy} or B was less than B_{msy}, and periods where both F was greater than F_{msy} and B was less than B_{msy}. These periods were consistent with the groundfish stock management regimes used in the assessment of the spatial-temporal distribution of juvenile Halibut (Boudreau, these proceedings).

Atlantic Halibut is now the most valuable groundfish fishery in the Maritimes, Canada. As this stock continues to be supported by the recent high recruitment, the fishery can be expected to expand for the next 5 to 10 years (Cox et al. 2016). The southern Grand Banks and Scotian Shelf Halibut stock is data poor compared to other key groundfish stocks and has had very few quantitative population models fit to the data. In the near term, the assessment of this stock will continue to benefit from improved catch and survey data collection and management. A better understanding of the stock-recruitment relationship will provide more biologically relevant performance indicators and help to assess stock status and impacts of the fishery on the stock. Given the increases in TACs in this large management unit, any reproductive spatial structure, coupled with heterogeneity in demographic rates or heterogeneity in fishing mortality, could lead to enhanced risk of local overexploitation. A better understanding of Halibut stock structure and

demographic rates can be achieved by more careful examination of the RV survey Halibut catches, tagging, and the development of research programs that would involve other lines of evidence such as genomics and otolith chemistry.

Discussion

A participant asked how the sex ratio based on landings was derived. The Science Lead responded that this is based on Observer data, which is largely from the DFO-Industry Halibut survey and commercial index. The participant responded that Pacific Halibut models were very sensitive to an assumed sex ratio. Pacific Halibut can be sexed using genetics, but this is not possible in Atlantic Halibut. The participant then asked if the DFO-Industry Halibut hook spacing was standardized, and the Science Lead responded that it is not. Another participant indicated that the catch observed on boats differed in size structure than that observed at the wharf. A participant then asked over what time period the growth model used in the assessment was developed. The Science Lead responded that the data used in the growth model was from all the otoliths aged before 2007.

The discussion then focused on Reference Points and natural morality. A participant asked when the rebuilding target was set for the stock and if it had been revisited since it was initially set. The Science Lead replied that current Reference Points for the stock were established in 2014. The current Upper Stock Reference (USR) is the Spawning Stock Biomass (SSB) in 2013, which is considered an interim reference point. A participant inquired about the approach to identifying the USR and why 0.8 B_{msy} had not been used. The Chair noted that that approach had not been accepted at the framework peer review meeting because, according to the model results, spawning stock biomass could potentially continue to grow significantly in the long term, and had the USR been based on the model B_{msy}, it would have been set at a higher level than has been seen throughout the 40 year time series, such that despite the increase in the population abundance a more cautious management approach would be applied. Last, a participant asked if natural mortality was estimated in the assessment model. The Science Lead indicated that a tagging-based natural morality is used in the first phase of model fitting and then natural mortality is fit to males and females separately in later phases. The participant followed up, inquiring if seals were believed to have an effect on the stock. The Science Lead indicated that there does not appear to be an indication that Halibut is a major prey item of seals, although there is limited diet analysis for seals that would allow this to be assessed.

Presentation: From the Other Coast: Pacific Halibut from California to the Bering Sea: Biology and Management Don't Mix

Science Lead: B. Leaman
Rapporteur: K. Curran

Summary

The International Pacific Halibut Commission (IPHC) conducts research and recommends management measures for Pacific Halibut throughout its range off the west coast of North America. Management is effected through catch limits for individual regulatory areas, which have evolved in concert with the spatial and temporal development of the fishery. These areas do not have a biological basis but provide the spatial framework for management actions. Tagging studies for Pacific Halibut have revealed high levels of ontogenetic movement among the regulatory areas, largely in an eastward and southward direction from the juvenile settlement areas in the western portion of the stock range. Additionally, the fish undertake seasonal spawning migrations that complicate the understanding of any relationship between area-specific spawning biomass and subsequent recruitment. These migrations also create the potential for among-area fishery interceptions, if the fisheries are prosecuted during those time

periods. However, there is little information about the rates of spatial movement by the youngest (2-5 year) fish, other than recognizing that such juvenile fish from the Bering Sea can be anywhere in the stock range within 3-5 years after tagging.

To cope with this underlying stock mobility, the IPHC staff has developed a number of innovative analytical approaches to stock assessment and management recommendations. These approaches utilize multiple information sources, an ensemble of assessment models, a risk-based decision table, and a comprehensive fishery-independent survey to apportion coast-wide biomass estimates into area-specific estimates.

Discussion

A participant inquired if multiple recaptures could be pursued. The Science Lead responded that this is not incorporated into the tagging studies and remains a challenge for such a large ranging stock. Another participant asked how spawning locations were found and identified. The Science Lead indicated this was done based on egg/larval surveys and tagging studies (winter-time tagging). The participant then asked if site fidelity was based on tagging results, and the Science Lead responded that it was. Last, a participant asked if all of this research is driven by historical declines in Pacific Halibut. The Science Lead noted that the more recent changes were, for example, due to rapid changes in stock indices (e.g., size-at-age).

A participant sought more information about spawning areas, particularly in consideration of seasonal effects. The Science Lead indicated that Pop-Up Satellite Archival Tags (PSAT) tag information demonstrated spawning behaviour (e.g., spawning rises), which could be used to interpret spawning at location. It was noted peak spawning occurs in January for Pacific Halibut. A complication of PSAT tags, however, is that some fish appear to skip spawning. The participant asked if spawning influenced the ability to recapture and the Science Lead noted that the fishing is closed during the spawning season. Another participant asked how the time before spawning and larvae were determined. The Science Lead noted that this was based on extensive surveys. The Science Lead subsequently noted that seasonal closures of the fishery were implemented to allow for movement of fish to spawning grounds and not necessarily to protect fish during spawning.

Presentation: Atlantic Industry Perspective: Who We Are and What We Have Learned from the Longline Survey

Science Lead: K. Vascotto
Rapporteur: K. Curran

Summary

The structure of the fishery and how quota is allocated amongst the different fleets was reviewed. The Presenter noted that the <45 foot fishing vessels now move further offshore (traditionally inshore boats). In general, catch is focused in the fixed gear sector using smaller vessels. The role of the Atlantic Halibut Council was then summarized. The council consists of harvesters and processors (i.e., individuals interested in viability of the Halibut fishery), with its overall role in the fishery having changed over time. The Presenter discussed issues associated with logbook completion and Observer coverage, noting that Industry has seen Halibut abundance and distribution increase over the past couple of decades (catch rates going up and areas of occupation increasing). Last, the DFO-Industry Halibut Survey was reviewed. The survey consists of 50 'golden sites' (fished every year), 170 additional fixed sites, and other opportunistic survey locations (commercial index). It was noted that Industry continues to work closely with DFO to ensure long-term viability of the Halibut fishery in Atlantic Canada.

Discussion

A participant asked if the fixed stations of the DFO-Industry Halibut Survey are fished every year. The Presenter noted that only the 50 golden stations are fished each year and the other 170 fixed stations are not necessarily fished each year. The overall survey stratification scheme has demonstrated that lower quality habitat is demonstrating improvement of Halibut presence/abundance. The participant then asked what the basis was for the original stratification scheme, and the Science Lead replied that commercial fishing catch rates were the basis for survey design. Another participant asked if the discard of large fish was due to market conditions. The Presenter responded that this cannot be determined with certainty, but noted the observed trips exhibit larger fish relative to what is landed at the wharf (suggesting larger fish are captured but not necessarily retained for landing). A Science Lead noted that simulation modeling at the recent assessment demonstrated no response to the discard of 'whale-sized' fish in the assessment results, although the model does not capture all the dynamics of larger fish; for example, it assumes a constant relationship between spawning potential and size.

A participant asked if different fecundity was included in the assessment model and the Science Lead responded that it was not. Another participant recommended that the proposed search for 'variation in growth' be down-weighted in terms of research priorities, as this is likely to occur at large scales (productivity changes) but not likely to say anything meaningful at small scales. This was supported by another participant, who indicated that growth is highly-variable for Pacific Halibut, although it was noted that growth can be teased out from size-at-age observations. A Science Lead asked if tagging results could be used to say something about growth, and the participant noted these data are not insightful for growth of Pacific Halibut.

A participant asked if juvenile recruitment in low quality habitat areas could be evaluated, in order to further explore the expansion of 'area of occupancy'. The lead responded that this type of question could be considered further in a new survey design. Last, there was a discussion regarding differences between the RV survey and DFO-Industry Halibut Survey, and it was noted that this may be due to the difference in fish size each survey captures: juvenile and adult, respectively. It was suggested that three-year lag between the two surveys might exist, and this will be explored as more data becomes available (the current signal is a unidirectional increasing trend, and one would need more ups and downs to identify a lag).

DISTRIBUTION AND MOVEMENT (TAGGING STUDIES)

Presentation: Recovery of the Gulf of St. Lawrence Atlantic Halibut Fishery to a 50-year High: Data Needs and Collaborative Research Opportunities

Science Lead: H. Murphy
Rapporteur: K. Curran

Summary

The Gulf of St. Lawrence (NAFO Divisions 4RST) Atlantic Halibut fishery is an historically exploited fishery that is currently experiencing its highest landings since the 1950s. The TAC has tripled since 1988 and is now 1036.8 t. RV multispecies trawls, which catch mainly juvenile fish (<100 cm), and commercial catch per unit effort indicate a healthy stock. However, this 'Gulf' Halibut stock is managed in a precautionary manner due to lack of data on spawning stock biomass and exploitation rates. In contrast, the 'southern' Atlantic Halibut stock (NAFO Divisions 3NOPs4VWX5Zc) has been the focus of an extensive multi-year conventional tagging program and widespread sentinel longline survey, which has allowed DFO to estimate exploitation rates, describe the movements and spatial distributions of Halibut, and estimate their population size. Data needs in the Gulf include basic biology of Halibut (e.g., spawning

stock biomass, spawning locations, nursery areas, length-at-age); development of a stock assessment model; and further investigation of potential stock substructure (e.g. tagging, genetics, otolith microchemistry).

There have been 2 conventional tagging programs in sub-regions of the Gulf (around Anticosti Island and Div. 4R) (Figure 2). Both studies found that tag recaptures were within or just outside the Gulf, close to the original tagging locations, with few exceptions (1 tag recaptured in Iceland and one tag recaptured on the Scotian Shelf). These results are similar to tagging studies of the southern stock, which also found few recaptures outside of the southern management area (e.g., only 7 fish recaptured in the Gulf). During the most recent tagging program in the Gulf (1998-2011), tagging and recaptures occurred during the commercial fishing period (May-September) so information on seasonal changes in distribution is lacking. The locations of tag recaptures also suggests stock sub-structure within the Gulf, with limited movement found between the northern (NAFO Divisions 4RS) and southern (NAFO Divisions 4T) Gulf. Growth rate for Gulf Halibut was 9.0 cm/year (majority of Halibut were < 85 cm), which is similar to the southern stock (9.4 cm/year for Halibut <100 cm). Time at liberty peaked at 1, 2, or 3 years, which was similar to the southern stock. Median distance travelled was 76 km, which is a greater median distance than the southern stock (27 km), even though the Gulf is a smaller management area.

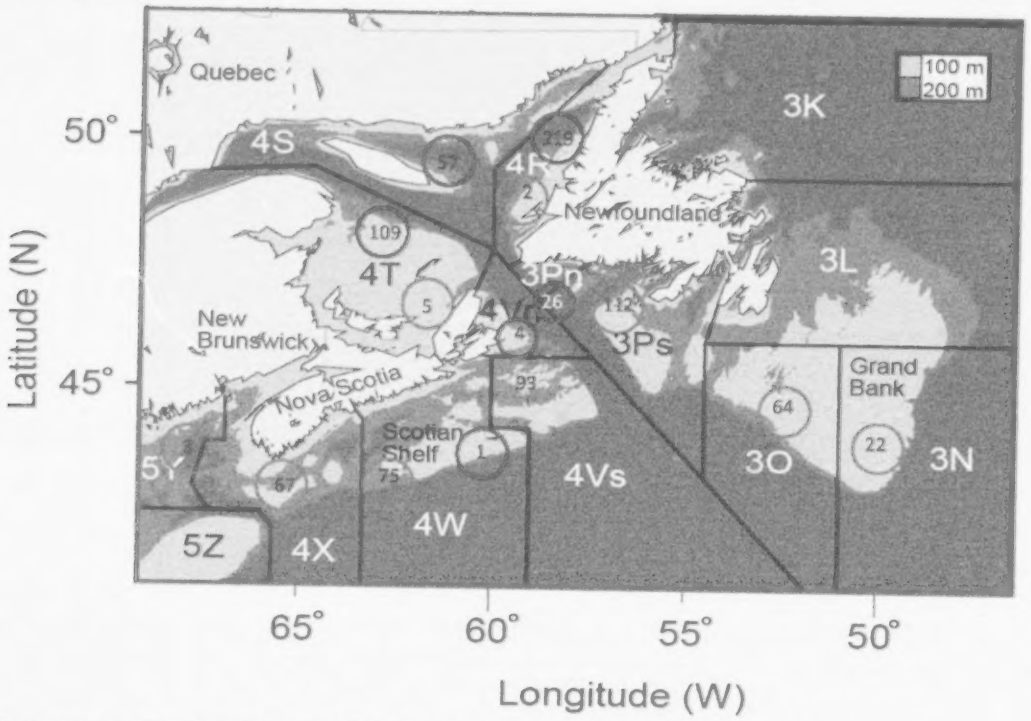

Figure 2. Distribution of Atlantic Halibut conventional tag recaptures in NAFO Divisions 3NOPs4RSTVWX5Zc. Number of tag recaptures circled in black indicates Halibut that were originally tagged in NAFO Divisions 4RST; number of tag recaptures circled in grey indicates Halibut that were originally tagged in NAFO Divisions 3NOPs4VWX5Zc (based on data from den Heyer et al. 2012).

Future research needs are for a Gulf-wide conventional tagging program and longline survey similar to the survey programs in the southern management area. Collaborations on Halibut research in the Gulf amongst Fisheries and Oceans Canada; Fish, Food and Allied Workers;

Department of Fisheries and Aquaculture (Newfoundland and Labrador Region (NL)); and academia (Memorial University, Gulf of Maine Research Institute) are ongoing. For example, all collaborators are involved in a satellite tagging research project on mature and juvenile Gulf Halibut to determine where larger and smaller Halibut are located year round, based on temperature, depth and geolocation data, and these data will be used in the design of a targeted tagging and longline survey of Gulf Halibut.

Discussion

A participant asked if recaptures by area could be re-adjusted by sampling effects (e.g., fishing intensity). The Science Lead acknowledged that this has not been looked at but could be explored further. Another participant asked about tag shedding and the Science Lead noted that the tags have shown better than 80% retention in Scotian Shelf and southern Grand Banks tagging surveys, although this has not been evaluated for Gulf of St. Lawrence tagging surveys as the tagged fish were not double tagged. A participant then asked if fishing seasons are the same on the Scotian Shelf and southern Grand Banks and Gulf of St. Lawrence, wondering if this could affect tag recovery. The Science Lead noted that the Scotian Shelf and southern Grand Banks fishery operates year-round, while the Gulf of St. Lawrence fishery is seasonal (ice poses challenges). Last, a participant asked why there were no tagging data for large fish in the Gulf of St. Lawrence survey, and the scientist noted that industry is not looking for larger fish in this fishery (not marketable), although large fish are known to exist in this area.

A participant provided additional comments on the tagging study, clarifying that tagging occurs in the fall, focused on certain areas in the Gulf of St. Lawrence. There was then discussion of how the Gulf of St. Lawrence tagging results could be compared to the Scotian Shelf and southern Grand Banks tagging results, given they occur at different times of year. A participant asked if occurrence of the fall tagging survey in the Gulf of St. Lawrence considered positioning of Halibut in the water column, for comparison to Scotian Shelf and southern Grand Banks tagging results that occurs earlier in the season (spring). The Science Lead responded that it is believed Halibut are higher in the water column in spring and lower in fall, although in the Gulf of St. Lawrence there is a water depth limit of 500 m, so the difference in the survey timings does not appear to have an effect. The Chair questioned whether, given that the Gulf of St. Lawrence longline survey is in the planning stage and that the existing Scotian Shelf and southern Grand Banks is in review, had there been any effort between the two regions to either

1. look at standardizing the two surveys so the indices could be compared, or
2. learn from the existing survey and survey review on the Scotian shelf and Grand Banks in planning the survey in the Gulf.

A participant indicated that each survey should be designed with the data needs in mind (e.g., their respective stock assessments), but not necessarily for comparative purposes.

Presentation: Effects of Pop-up Satellite Archival Tag (PSAT) Temporal Data Resolution on Interpretations of Behaviour, Vertical Habitat Use and Movement

Science Lead: J. Fisher and D. Robert
Rapporteur: K. Curran

Summary

In the context of better understanding the spatial structure, habitat use and behaviours of Atlantic Halibut, electronic tags are increasingly relied upon to provide depth, temperature and geolocation data over periods spanning days to more than a year. However, the effects of temporal data resolution on interpreting fish behaviours are questions fundamental to research

programs using electronic tags with finite data storage and data transmission capacities. Quantifying such effects requires multiple temporal resolutions and in pop-up satellite archival tags (PSATs), data transmissions via satellite are limited (Figure 3), such that temporal resolution is a decreasing function of the deployment duration. Physical recovery of PSATs overcomes this limitation, providing data on temperature, depth, etc. at rates at least 15-30 times greater than transmitted data. Using PSATs physically recovered from large (>107 cm) Atlantic Halibut in the Gulf of St. Lawrence, Canada, we quantified the effects of data resolution (2 min., 30 min., 60 min.) on interpretations of vertical movements including rapid ascents during the expected spawning season. Putative 'spawning rises' of 6-20 minute durations were only present within highest resolution data (Figure 4). Previously proposed methods using variance in depths >25 m within 6-hour periods to detect spawning rises in Atlantic Halibut yielded dozens of apparent false-positives within the expected spawning season, relative to those estimated from the high resolution data series.

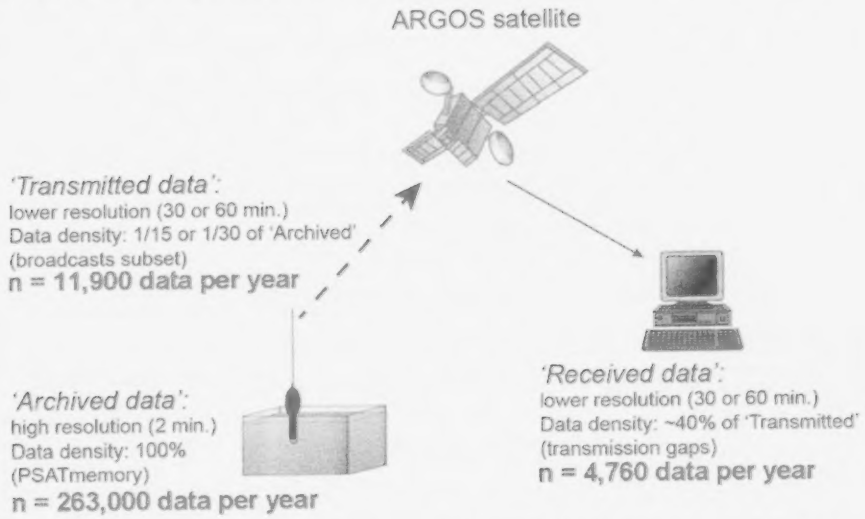

Figure 3. An example of the three types and volumes of data derived from pop-up satellite archival tags (PSAT) that are archived, transmitted, and received from a Microwave Telemetry, Inc. 'X-tag' deployed for 1 year. 'Archived data' represent the highest temporal resolution, continuous data series as the PSAT samples the environment once every 2 minutes. 'Transmitted data' represent a subset of archived data, processed by the tag's programming to yield data every 30 or 60 minutes that are sent to the Argos satellite. 'Received data' are the subset of transmitted data (with gaps) that are successfully relayed through the Argos satellite. Data throughput limitations ultimately limit received data.

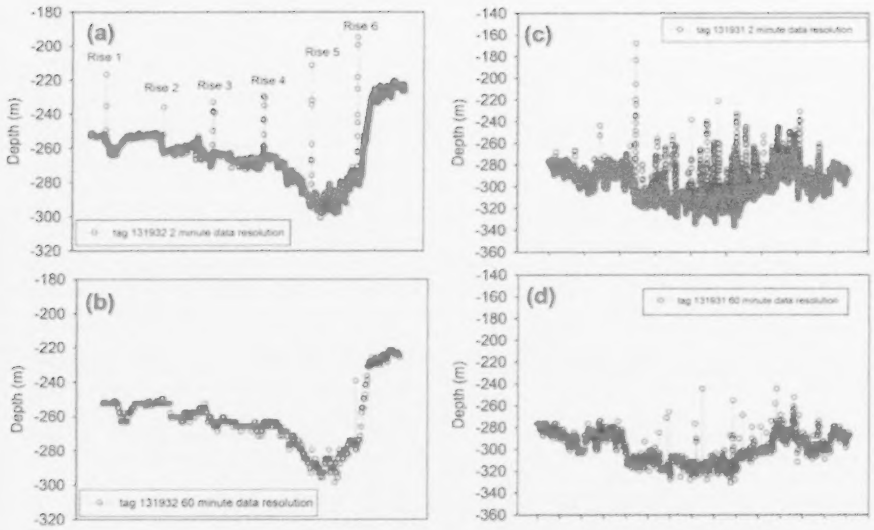

Figure 4. The effects of data resolution on the detection and interpretation of putative spawning rises in two Atlantic Halibut from recovered PSATs. (a) PSAT 131932 'Archived' data series from February 8, 2014, to March 1, 2014, at a 2 minute data resolution. (b) PSAT 131932 'Transmitted' data series from February 8, 2014 ,to March 1, 2014, at a 60 minute temporal resolution. (c) PSAT 131931'Archived' data series from January 1, 2014, to February 28, 2014, at a 2 minute data resolution. (d) PSAT 131931 'Transmitted' data series from January 1, 2014, to February 28, 2014, at a 60 minute temporal resolution. These panels illustrate that most of the rapid ascents and descents (on the order of 6-20 minutes) in (a, c) are absent from the transmitted data series (b, d).

Given these results, we conclude that PSAT temporal data resolution strongly affects pattern detection in Atlantic Halibut, particularly events of short durations including spawning rises (Figure 4). However, also highlighted were new technologies that have facilitated PSAT recoveries at-sea (Figure 5). Those technologies were first used successfully in the Gulf of St. Lawrence in 2014 and then expanded to recover the majority (13 of 16) of PSATs from Gulf Atlantic Halibut in 2015. Given the high temporal resolution depth and temperature data obtained from recovered PSATs, they facilitate the application of spatial movement reconstructions for individual Atlantic Halibut to identify spawning sites and uses of the Gulf of St. Lawrence habitats over an annual cycle. Such information has been presented within the Gulf of St. Lawrence Atlantic Halibut assessment (2015) and provides new insights into the spatial structure and habitat use by individuals subjected to a growing and lucrative fishery. These lessons learned in the Gulf of St. Lawrence are directly transferrable to other jurisdictions in which Atlantic Halibut electronic tagging programs are planned or have been implemented.

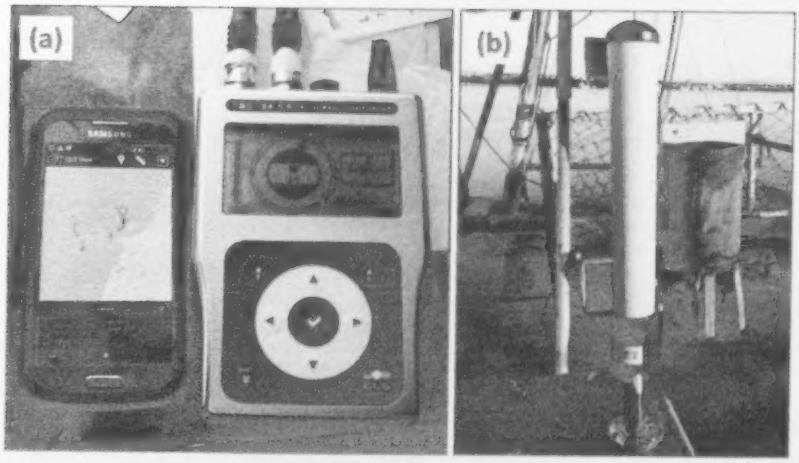

Figure 5. New technologies facilitate PSAT recoveries at-sea. (a) Illustration of the CLS View Android Application running on a cell phone and showing the locations of four PSATs floating at the surface (left) beside the CLS RXG135 receiver (right). Both products are made by CLS America, Inc. (b) The RG58 directional antenna mounted above the bridge of a 45-foot longliner. The white protruding cone above the silver base plate is the 0-degree reference for all angles. In combination, these products facilitated the rapid recovery of five PSATs at-sea and subsequent analyses of the effects of temporal resolution on the detection and quantification of rapid, episodic vertical fish movements.

Discussion

A participant asked how long a PSAT tag could be detected once it pops off a fish and surfaces, and the Science Lead indicated that one has a two-week window to recover the tag once it is first detected until it is no longer detectable. Another participant asked why a rapid rise in depth observed in tagging data is considered to be indicative of spawning and not feeding and the Science Lead noted that this assumption is based on the known behaviour of other flat fish, as well as that the behaviour was observed to occur during the spawning period known for Atlantic Halibut. Last, a participant inquired about the seasonal resolution of the transmitted data and if this led to false-positive observations. The Science Lead responded that the resolution of data transmitted is resultant of a proprietary algorithm and is not adjustable.

Presentation: Habitat Associations, Seasonal Movements, and Population Structure of Atlantic Halibut in the Gulf of St. Lawrence Inferred from Pop-up Satellite Archival Ttags (PSAT)

Science Leads: D. Robert, J.A.D. Fisher, H.M. Murphy, A. Le Bris, P.S. Galbraith, M. Desgagnés, M. Castonguay, and T. Loher
Rapporteur: K. Curran

Summary

Atlantic Halibut is the most valuable fish per unit weight in the Canadian Atlantic fisheries. In Canadian waters, Atlantic Halibut is managed as two separate stocks: Gulf of St. Lawrence (NAFO divisions 4RST; hereafter Gulf) and the Scotian Shelf and southern Grand Banks (NAFO divisions 3NOPs4VWX5Zc; hereafter southern). In 2014, Gulf Halibut made up 39% of landings in the Canadian Atlantic Halibut fishery (DFO 2015c). The Gulf stock is considered healthy, based on increasing catch rates of juvenile Halibut by the DFO research vessel multi-species trawl survey and recent high commercial catch rates. Based on these indices, total allowable catch (TAC) has tripled since 2006. However, the lack of a reliable index of abundance remains

a major knowledge gap for the assessment of the resource, and the design of a dedicated abundance survey requires more information related to the distribution, seasonal migrations and habitat use of Gulf Halibut. In contrast, the southern Atlantic Halibut stock has been the focus of an extensive multi-year conventional tagging program and widespread sentinel longline survey, which has allowed Fisheries and Oceans Canada to estimate exploitation rates, describe the movements and spatial distribution of Halibut, and estimate population size. Increased knowledge of southern stock population structure and biomass contributed to the fishery obtaining Marine Stewardship Council (MSC) certification in 2013, which can increase market access and landed value to harvesters.

To support DFO efforts in designing a similar longline survey for the 4RST Halibut stock, the Centre for Fisheries Ecosystems Research led the deployment of pop-up satellite archival tags (PSATs) on juvenile and adult Halibut in NAFO Division 4R in the autumns of 2013, 2014 and 2015. PSATs record depth, temperature, and light data at a high temporal resolution. The advantages of using PSATs over conventional tags or other electronic tags are that they provide fine temporal scale data on habitat use by individual fish within and (potentially) beyond the stock's assumed management boundaries throughout the year. PSAT data can also be recovered independent from fishing effort as tags release from the fish after a preprogrammed time interval and transmit data through the Argos satellite network. These data can yield valuable information on spawning locations, stock structure, movement patterns, and other behaviours at the individual level. A total of 60 PSATs have been deployed on Halibut in the 85-174 cm size range over a 3 year period from 2013 to 2015. To date, data from 2013 deployments (n=20), which yielded data from 15 Halibut >107 cm, have been analyzed. This included high-resolution data from 6 PSATs that were physically recovered. Using a geolocation model developed for the Gulf of St. Lawrence, seasonal migrations were reconstructed for these 6 individual Halibut.

Gulf Halibut migrated to deeper waters following tagging in October to the onset of the spawning season in January (Figure 6). Mean depth during the January-March period was of ca. 250 m. Water temperature at these depths ranged between 5.5 and 6.0°C (Figure 6). Halibut progressively moved back to shallower and colder waters from April and reached depths <100 m in July. These patterns were strikingly different from those reported for the southern stock with fish distributing in waters deeper than 500 m during winter and deeper than 200 m year round (Figure 6). Based on modeled trajectories from recovered PSATs, Gulf Halibut overwintered in the deep Esquiman, Laurentian and Anticosti channels, and returned to coastal areas of the Gulf from May to September. Putative spawning rises detected in 2 individuals occurred in the Esquiman channel (Figure 7). There was little evidence that PSAT-tagged individuals migrated outside of the Gulf management area, with the exception of one PSAT that popped off near Burgeo (NAFO Division 3Ps). These results, combined with information that will be obtained from 2014 and 2015 deployments, are facilitating the design of a longline survey for the Gulf by providing new information on the depth strata that should be targeted at different potential times of the year.

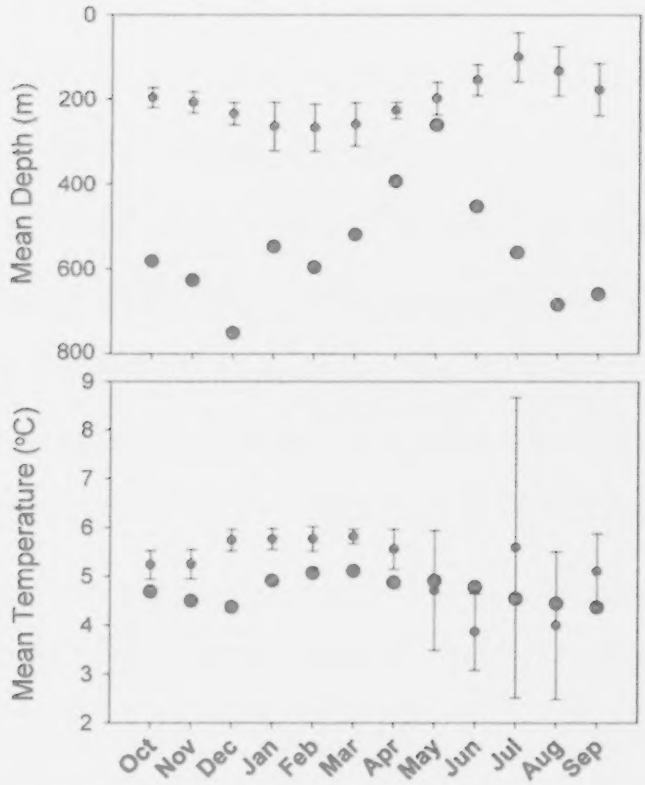

Figure 6. Monthly mean depth (top panel) and temperature (bottom panel) recorded by 15 PSATs over the period from October 2013 to September 2014 (in black), and by 17 PSATs deployed on Halibut from the southern stock (in red), as reported by Armsworthy et al. (2010). Error bars represent the standard deviation on the mean.

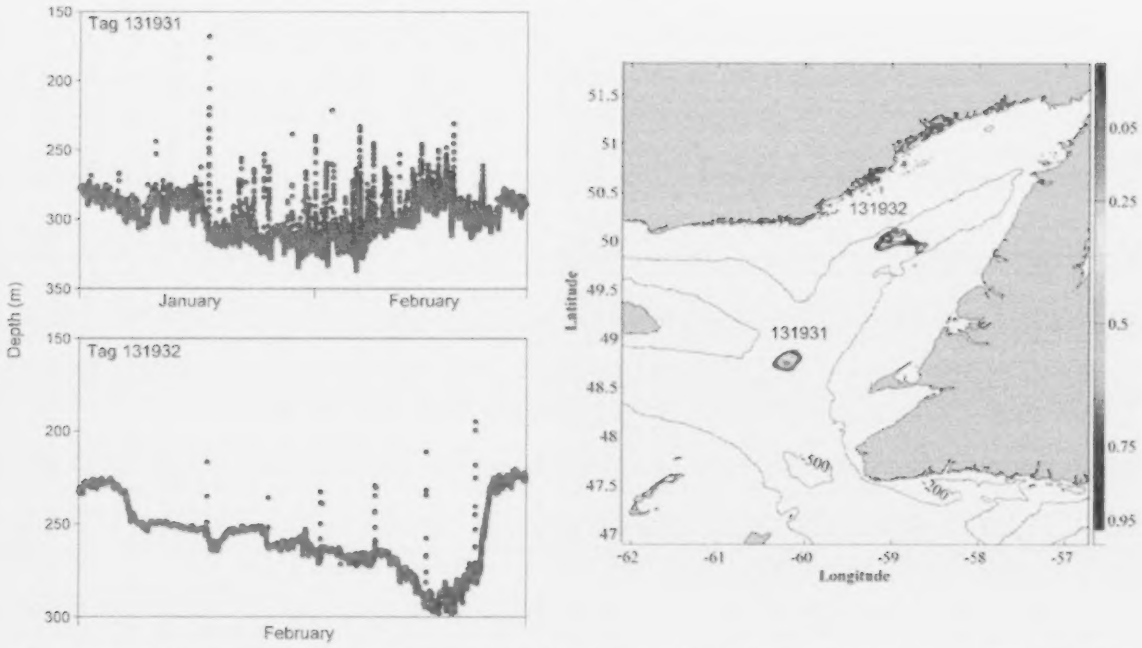

Figure 7. Left: depth profiles for 2 individual Halibut showing putative spawning rises in January-February 2014. Right: probability distribution function given by the geolocation model for tags 131931 and 131932 during the periods when spawning rises were observed (131931 from January 1 to February 28; 2014; 131932 from February 8 to March 1, 2014).

Discussion

A participant inquired if the geo-location modeling was only associated with tags physically recovered or if it could be applied to tags that only have transmitted data. The Science Lead indicated that the model attempts to reconcile data gaps associated with transmitted data (compared to archived data), but yields multiple possible locations of a fish during periods of data gaps. As such, model provides some information but not the whole picture. The Science Lead emphasized the importance of recovering tags to obtain archived data rather than relying on transmitted data for use with the geo-location model. A participant indicated that it would be interesting to include prey fields associated with geo-location modeled seasonal behaviours as a backdrop to provide further context of observed behaviour, as observed behaviour does not appear to be driven by temperature and depth alone (feeding is another major driver). The Science Lead acknowledged this point, agreeing that it is something worth pursuing. The Science Lead noted that capelin and herring are observed in the same areas where the fish were observed to exhibit feeding behaviours.

A participant noted that Atlantic Halibut on the Scotian Shelf and southern Grand Banks are not known to occupy very shallow, coastal areas, as was observed in Gulf of St. Lawrence, and asked if similar behaviour was observed for Pacific Halibut. A participant responded that Pacific Halibut are known to occupy very shallow, coastal waters in the summer periods. Another participant asked what the preferred temperature is for Atlantic Halibut the Gulf of St. Lawrence and the Science Lead indicated that this remains unknown, although they are found at 5°C much of the year, 5°C is a large depth layer and therefore is not necessarily a preferred temperature. In general, meeting participants felt the presentation and results were very interesting.

Presentation: USA Perspective and Pop-up Satellite Archival Tag (PSAT) Plans for Atlantic Halibut on Georges Banks and in the Gulf of Maine

Science Leads: C. McGuire and D. Hennen
Rapporteur: K. Curran

Summary

Little is known about the status of US Atlantic Halibut stock. There is anecdotal evidence that Halibut biomass in what is now US territorial waters is depleted relative to its peak (likely before 1800). Landings data exist back to 1893, but are confounded with catches from what are now Canadian and international waters. The Northeast Fisheries Science Center (NEFSC) bottom trawl survey catches Halibut, but survey trends are inestimable due to noise caused by low sample size. Recent data collected by at sea Observers offers the potential for estimation of total mortality based on average size composition, but the time series is short and complicated by the unknown size selectivity of some of the gear used in the fishery. Key biological parameters such as growth, maturity, sex ratio and fecundity are unknown. Connectivity with the larger stock in Canadian waters is unknown. Without additional research, there is little hope of determining the status of the Atlantic Halibut in the US.

In September 2015, a Halibut assessment 'update' was completed, but was determined by peer-reviewers to be unusable for determining stock status and setting management targets. A recommendation was made at that time to undertake a Halibut benchmark assessment. The Nature Conservancy partnered with Cape Cod commercial fishermen and government and academic researchers to submit a proposal designed to address research useful for completing a benchmark assessment. Specifically the proposal seeks to investigate Halibut stock structure through the geolocation of data recovered from 20 pop-up satellite archival tags (PSAT) deployed off Cape Cod, and to investigate growth, maturity and reproductive dynamics from approximately 250 biological samples collected by fishermen. If funded, field work would begin in the spring of 2017.

Discussion

A participant provided a brief overview of findings currently in press for publication, which suggest there is spill-over of Atlantic Halibut from the Scotian Shelf to the eastern Georges Banks to Gulf of Maine area. Another participant asked where industry in Cape Cod and Maine believe the Atlantic Halibut they catch are coming from, and the Science Lead indicated it is believed they are from Scotian Shelf and southern Grand Banks stock (Canadian waters). A participant then inquired about the meta-population concept, wondering if anything is known about the time and location of spawning events in US waters. The Science Lead responded that nothing is presently known on this. Another participant asked about the historical context of the fishery and if present observations can be linked to historical data. The Science Lead indicated that there are only historical accounts and no historical data to validate the accounts.

A participant asked how a benchmark could be applied with such limited information. The Science Lead indicated that not much could be pursued at this time given the absence of knowledge regarding Atlantic Halibut in US waters; however, it is possible that a benchmark could be pursued in 4-5 years when more is known from proposed PSAT studies on geo-location. Another participant inquired about historical tagging information, noting it appears to flow in one direction from the coast of Maine eastward (not southward). The Science Lead acknowledged this observation, noting that PSAT tags should provide more definitive information, as there is less of a concern with tags not being returned (satellites demonstrate where tags are in near real time).

Presentation: History of Tagging on the Scotian Shelf and Southern Grand Banks

Science Lead: N. den Heyer
Rapporteur: K. Curran

Summary

Atlantic Halibut are a large long-lived flatfish. Compared to other groundfish, Halibut are easy to tag because they have high tag retention, high post-release survival, and low natural mortality. One Atlantic Halibut tagged off of Nova Scotia was recaptured 19 years post release. Atlantic Halibut typically have a left-skewed distribution of displacements between release and recapture, with many Halibut having small displacements and a few moving large distances. Over the many years of tagging, the interpretation of Atlantic Halibut movement has changed. McCracken (1958), based on the displacement of large Halibut tagged near Anticosti Island in the Gulf of St. Lawrence and southwest Nova Scotia in the late 1940s, concluded that large displacements of some Halibut, including some as far as Iceland, were possible but that the majority of Halibut were recaptured near where they were tagged. Subsequent tagging studies (Jensen and Wise 1961, Kohler 1964) in southwest Nova Scotia and on the eastern Scotian Shelf near the Gully (Kohler 1964) documented a higher proportion of long distance displacements and concluded that Atlantic Halibut are highly migratory and that the dominant movement was eastward. Stobo et al. (1988) assembled most of these tagging studies and others and reported much larger displacements for Halibut less than 75 cm than greater than 75 cm and a decline in the rate of movement (defined as displacement/month) with size at the time of release.

A careful reanalysis suggests that the conclusion that large Atlantic Halibut did not move as far as small Atlantic Halibut was overstated, although there does appear to be a weak negative correlation between the size at the time of release and the rate of movement (Figure 8). Stobo et al. (1988) proposed countercurrent migration of Atlantic Halibut, which was the accepted understanding of Pacific Halibut movement at that time, whereby the early life history stages were swept by currents from spawning on the shelf edge of eastern Scotian Shelf and southern Grand Banks to southwest Nova Scotia, and a return countercurrent migration of juveniles to these spawning areas. Subsequent tagging deployments in the Gulf of Maine (Kanwit 2007) found a large proportion of recaptures to the east in Canadian waters, but did not find evidence for smaller Atlantic Halibut being more mobile. In 2006, the Atlantic Halibut Council began the Halibut All-sizes Tagging program (HAST) to estimate population size, exploitation rate and evaluate the movement of Atlantic Halibut within the Scotian Shelf southern Grand Banks management unit (den Heyer et al. 2012). Since 2006, 3882 Halibut have been tagged and released across the management unit during the Halibut longline survey in May-August. The displacements do not show a strong eastward bias or support the conclusion that smaller Halibut are more likely to have larger displacements.

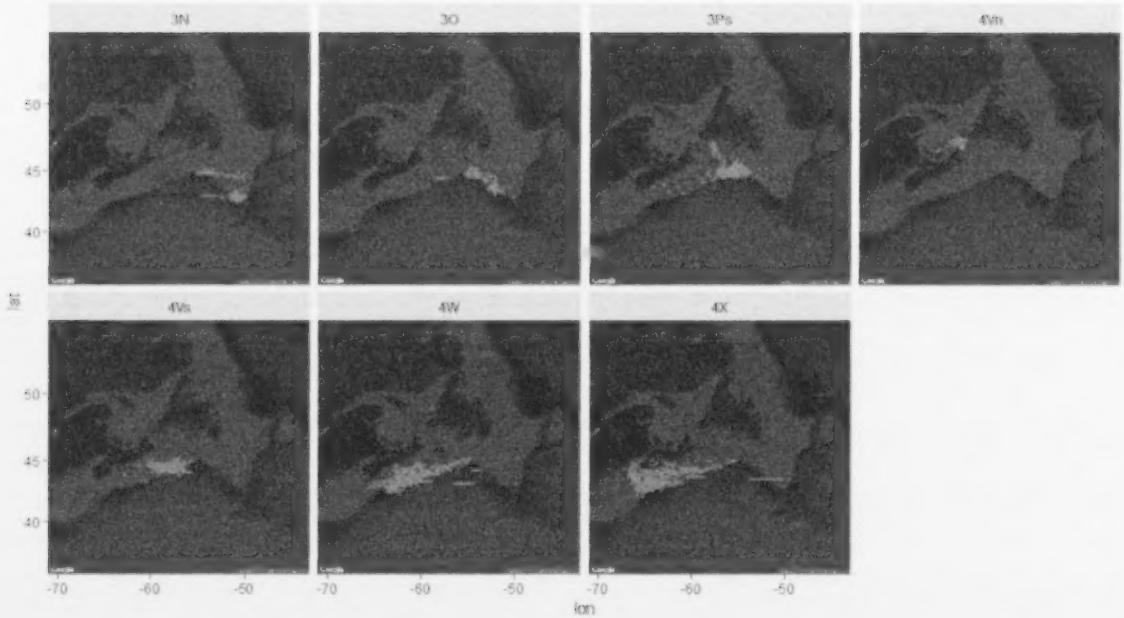

Figure 8. Maps of the displacement between release and recapture by NAFO area of release.

Although, some Halibut are recaptured large distances from the release sight, most (401 of 621 or 64%) of the Halibut tagged are recaptured in the same NAFO area in which they were released (Table 1).

Table 1. The number of Atlantic Halibut returned in NAFO area by the NAFO area of release. Bolded numbers delineate tagged Halibut that are recaptured in the same NAFO area.

NAFO	0B	3N	3O	3P	4R	4T	4V	4Vn	4Vs	4W	4X	5Y	Total
3N	0	**17**	46	5	0	0	0	0	0	0	3	0	**71**
3O	0	3	**22**	9	1	0	0	0	2	1	0	0	**38**
3Ps	0	2	10	**115**	0	0	0	3	11	2	3	0	**146**
4Vn	1	0	0	1	2	6	1	**23**	1	0	0	0	**35**
4Vs	0	0	0	9	0	0	0	1	**68**	19	0	0	**97**
4W	0	4	0	11	0	0	0	1	12	**80**	13	0	**121**
4X	0	1	2	6	0	0	1	0	6	18	**76**	3	**113**
Total	**1**	**27**	**80**	**156**	**3**	**6**	**2**	**28**	**100**	**120**	**95**	**3**	**621**

A preliminary analysis of this data suggests that there may be seasonal movement on and off the Scotian Shelf, but it is not conclusive. Overall, the conclusions from these tagging studies are limited because the distribution of fishing effort, spatially or seasonally, has not been formally assessed. More careful analysis on the 2006 to present HAST data and the older tagging data assembled by Stobo and Fowler (2006) is required to better understand stock structure. A seasonal analysis would also be informative.

Discussion

A participant suggested that the fish are typically recaptured a year later, noting that the seasonal boxplot may be more meaningful if presented as per release. Another participant suggested that the data could be corrected for 'days at liberty' per fish size, as, at a certain size, days at liberty might become influenced by natural mortality. It was then suggested that the

movement data could be overlaid with fishing effort, in order to determine the probability of recapture. The Science Lead acknowledged that this could be done, but that seasonal factors would need to be considered in such an analysis, e.g., look at one month at a time. The point was also made that movement would be underestimated because it is not known where the fish travelled in between tagging and recapture, and that this would be especially relevant if there are large seasonal movements and the fish are captured and tagged at the same time of year.

A participant noted that few the Halibut tagged in Canadian waters were recaptured south of the Hague Line, which could result from a lack of fishing effort for Atlantic Halibut in US waters. The Science Lead further noted that the larger minimum size in US water may also impact reporting rates. Last, a participant noted that the tagging results could be used to estimate growth rates. The Science Lead indicated that this was estimated to be 9-10 cms per year from tagging since 2006 to 2012.

It was noted that although there was no increase detectable in the US RV survey, the US industry perspective is that the abundance in the US has been increasing in recent years. It was also noted that a new Cusk survey may provide a better index in the future.

STOCK STRUCTURE

Presentation: Changes in Juvenile Atlantic Halibut Distribution and Connectivity Through Decades of Fisheries Exploitation in the Northwest Atlantic

Science Leads: S. Boudreau, N. Shackell, N. den Heyer, S. Carson
Rapporteur: K. Curran

Summary

The historical fishing patterns of American fleets targeting Atlantic Cod (*Gadus morhua*) and Atlantic Halibut (*Hippoglossus hippoglossus*) suggests that local overfishing had occurred, and that subpopulation by subpopulation was sequentially depleted (Grasso 2008). In contrast to the fisheries driven decline of groundfish in the Northwest Atlantic over the last four decades (Frank et al. 2005), Atlantic Halibut have been experiencing population growth in Canadian waters since the early 2000s (DFO 2015a,b, Trzcinksi and Bowen 2016). This upward trend is supported by a period of high recruitment. Learning from the collapse of cod stocks, it is now understood that the spatial scale of fisheries management was much larger than the spatial scale of subpopulations. Lack of recovery of species, such as Northern Cod, has contributed to the renewed interest in re-examining spatial stock structure in fisheries science (Cadrin et al. 2013).

Approach: An analysis of juvenile Atlantic Halibut is presented here to examine evidence of spatial and temporal structure utilizing a hierarchical Bayesian spatiotemporal modelling approach (Carson and Mills Flemming 2014). Fishery-independent groundfish research vessel trawl survey data of juvenile Halibut from the US and Canada was analysed to explore the spatial and temporal patterns of juvenile Halibut abundance in the Northwest Atlantic over the last 44 years (approximately 1970-2013) across different Canadian fisheries management regimes. With no *a priori* assumption about international and fisheries management division borders, the models were employed to identify areas of high abundance, persistence, a measure of connectivity that changed over time, and an index of spatial variance. It is argued that the protection of persistent high density areas has the potential to contribute to the sustainability of a stock. Further, once identified, the same methods can be used to illustrate the abundance of juvenile Halibut on a smaller spatial scale to explore their persistence within the two high density areas, Southwest Nova Scotia and the Gully.

Focus was on three parameter estimates derived from the model: persistence (index of the similarity of the spatial pattern over time), connectivity (distance at which the temporal patterns are no longer spatially correlated), and spatial variance (magnitude of difference between high and low areas). These parameters were used to determine if the spatial structure corresponds to the current assumption of stock structure. The data were analysed in four time periods, based on fisheries management periods in Canada that roughly correspond to periods of high or low regional abundance.

- **1970-1977**: The years before the exclusive economic zone was established and there were more foreign fleets exploiting Canadian waters (n=8 years). Halibut presence (number of sets with Halibut) = 422, number of surveys = 9. The data here are essentially the Scotian Shelf.
- **1978-1989**: Post-implementation of the exclusive economic zone when most stocks rebounded in the absence of foreign fleets and while Canada's domestic fleet capacity was building. Additionally, the Halibut stocks and management areas were defined by DFO in 1988; n=12 years, Halibut presence= 1550, number of surveys 15.
- **1990-2003**: The first year for the NGSL trawl survey data is 1990. Also included in this time period are the moratoria on Newfoundland Atlantic Cod fishery in 1992 on groundfish on the Eastern Scotian Shelf in 1994 and on Gulf of St. Lawrence Cod in 1993, n=14 years, Halibut presence = 1310, number of surveys 16.
- **2004-2013**: This is a decade of high Halibut recruitment n=10 years, Halibut presence = 1649, number of surveys 15.

There were persistent high density areas over all 4 periods, although a few high density areas in the 1980s disappeared, and a few arose in the last decade (Figure 9). While the persistence parameter was high in all periods, connectivity and spatial variance varied (Figure 10). During the periods when the entire model domain was well sampled, connectivity was estimated at 230 and 440 km (Figure 10), an order of magnitude less than the distance assumed in the stock assessment (approximately 2000 km). To explore the long-term trends in the identified high density areas, models for the entire survey time series were fit to the two areas of persistent juvenile abundance: southwest Nova Scotia (Figure 11) and the Gully (Figure 12). Persistent patches within the high density areas were identified.

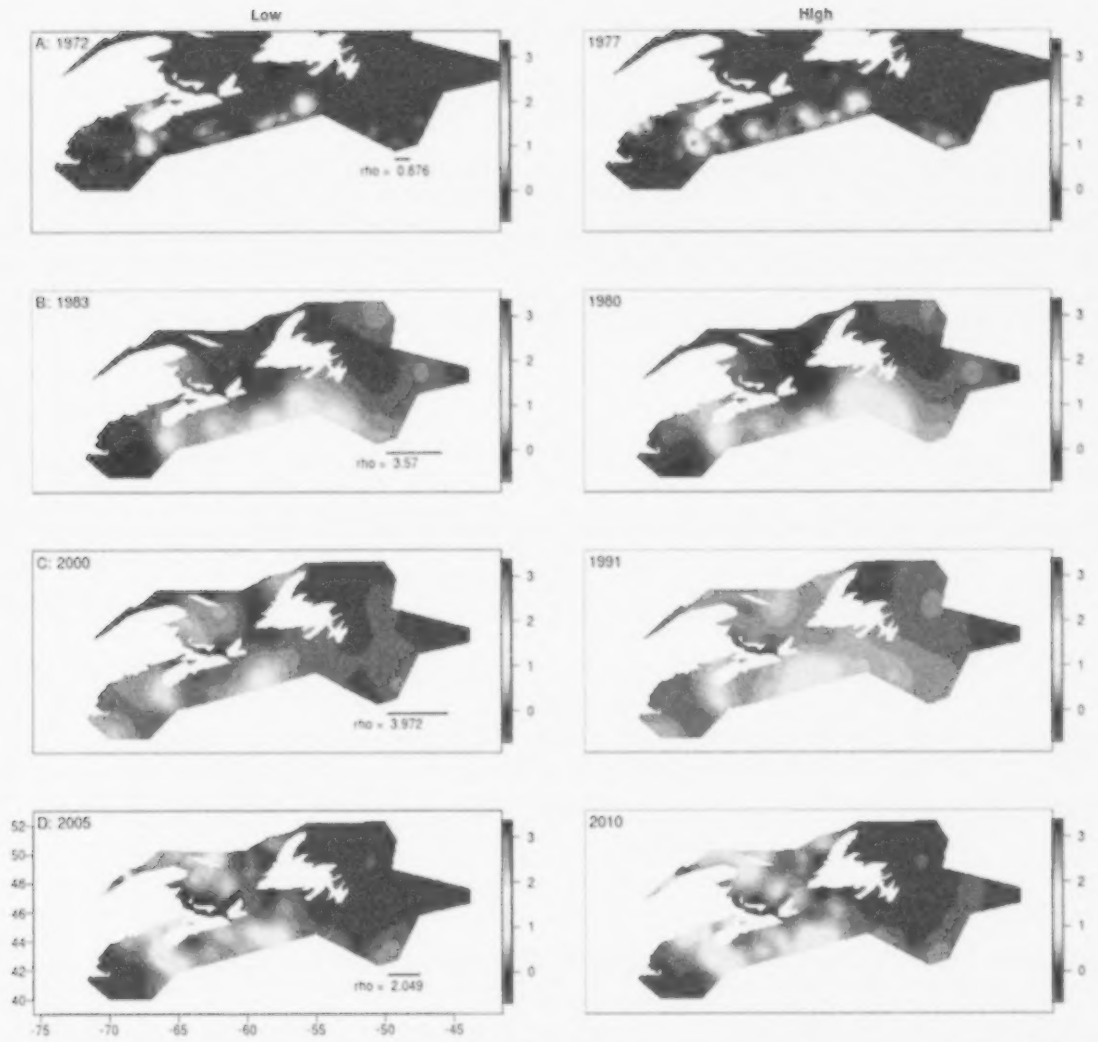

Figure 9. Random fields for the entire range. Legend for range parameter (rho, degrees) on map. Left hand column are low years in the model time period, right hand side is the high, note they are not in chronological order but displayed rather to illustrate the differences in low to high years. Models contain both Temperature and Depth using a Poisson likelihood on the positive data only. The colour scale illustrates the predicted Halibut abundance (random field) and is on the same log scale (min -0.6389 - high 3.297). Note: the model A (1970-1977) map is a smaller geographical area to represent the nature of the data being largely on the Scotian Shelf.

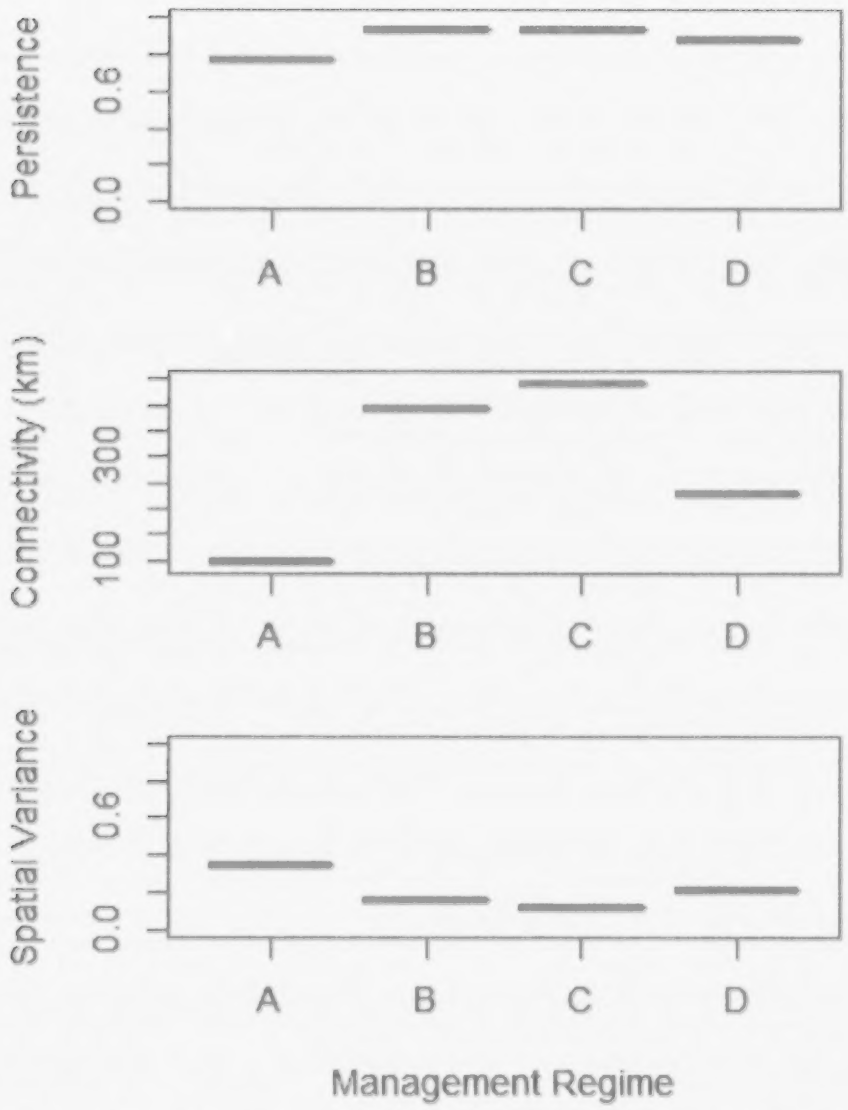

Figure 10. Entire Range model means across the four time periods illustrated in Figure 11 (time periods outlined in text above). Parameters presented are, Persistence (index of the similarity of the spatial pattern over time), Connectivity (distance at which the temporal patterns are no longer spatially correlated) and Spatial Variance (magnitude of difference between high and low areas).

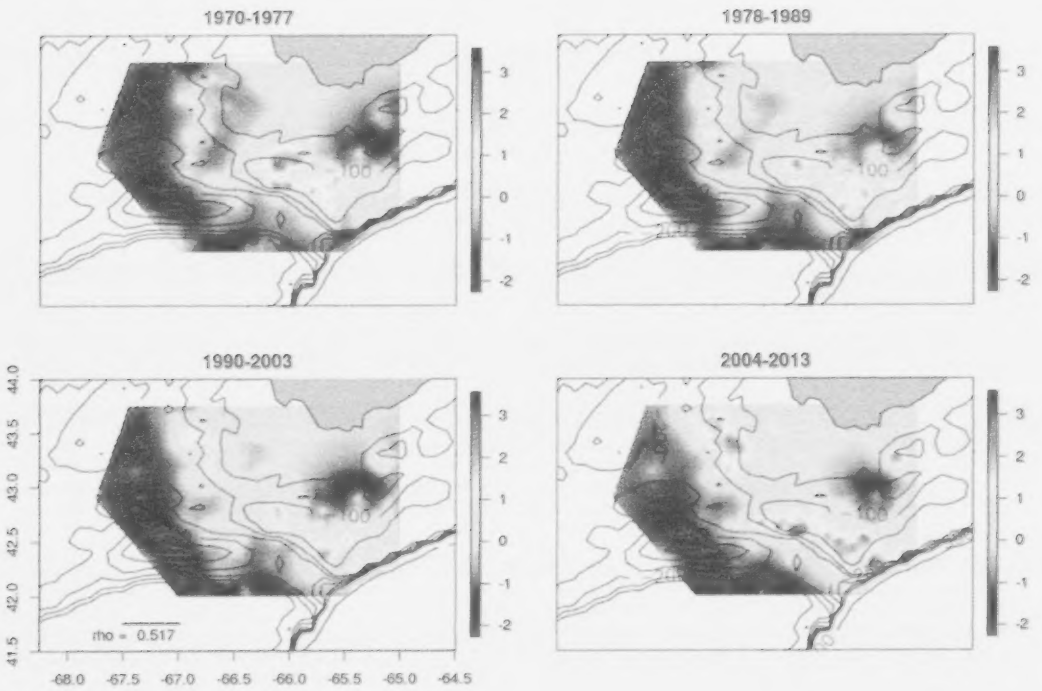

Figure 11. Southwest Nova Scotia Random Fields. Time steps are the management periods, data is all data, Zero-inflated Poisson1, covariates are Depth, Temperature, and Sediment. Range parameter (rho) in degrees is presented on 1990-2003.

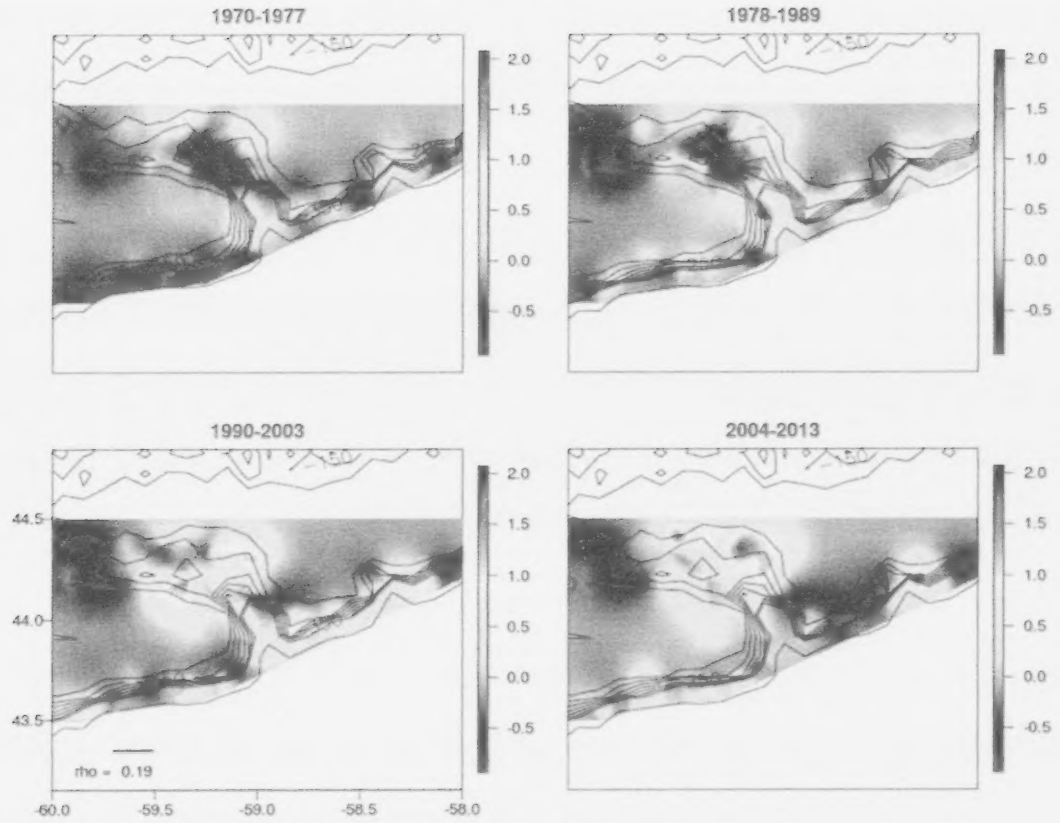

Figure 12. The Gully Random Fields. Time steps are the management periods, data is all data, Zero-inflated Poisson1, covariates are Depth, Temperature and Sediment. Range parameter (rho) in degrees on 1990-2003.

Juvenile Halibut exhibit a spatial structure in the NW Atlantic at a scale smaller than the current Halibut stock assumption within the Canadian fisheries management landscape. Our results present statistically independent persistent high-density areas of juvenile Halibut abundance, providing evidence that juvenile Halibut spatial structure is more complex than previously identified and has varied over the past four and a half decades. Two high density areas were consistently present throughout the time series, southwest Nova Scotia and the Gully. These analyses provided evidence that while some smaller patches of Halibut appear to be ephemeral, persistent patches appeared to be on the northeast slope of a deep channel or canyon, which may have afforded juvenile Halibut a refuge to increase their population growth.

Discussion

A participant asked how the model fits to data when RV survey does not occur in the same area each year, that is, the time series is not consistent between years due to missing data. The Science Lead noted that the model is built around one mesh that accounts for differences in survey locations between years. The participant then asked if connectivity would naturally decrease at lower densities due to greater differences in variability and the Science Lead indicated that it likely would. The Science Lead then noted that covariates were explored in the

analysis. The participant acknowledged the importance of this work and that similar work is being pursued for Pacific Halibut.

A participant asked about the higher density area of juvenile Atlantic Halibut located along the southern Grand Banks shelf break and a Science Lead noted that this was post-Exclusive Economic Zone (EEZ), when foreign fleets were no longer permitted to fish but domestic fleets were not large enough and did not have capacity to fish at this offshore location. There was then a question regarding permissible RV trawl surveys in the Gully Marine Protected Area. It was noted that Atlantic Halibut fishing is permitted in Zones 2 and 3 (not Zone 1), with a DFO-Industry survey sample location located in Zone 2 at the head of the canyon (on-shelf). It was further noted that the RV trawl survey is permitted in Zone 3 and portions of Zone 2 in areas unlikely to have corals, sponges, and seapens. The RV trawl survey is not permitted in Zone 1 (which is known to host sensitive habitat as well as damage gear).

A participant asked what data were used in the analysis for Gulf of St. Lawrence for the first two time periods and the Science Lead responded that no Gulf of St. Lawrence data existed, so the model could not be used to make prediction in the Gulf of St. Lawrence for these two time periods. Another participant suggested that the model could be separated by Scotian Shelf and southern Grand Banks and Gulf of St. Lawrence to address the variation in sampling effort. The Science Lead acknowledged that more exploration of the model could be pursued for the Gulf of St. Lawrence. It was acknowledged that the analysis is preliminary, but provides a lot of opportunity to explore spatial-temporal relationships of stock. The approach was supported by meeting participants. Further understanding of the underlying dynamics of the model is required.

A participant suggested that the approach could potentially be used for identifying spawning or nursery areas that could be seasonally protected. It was noted that, to some extent, the high density areas coincide with areas that are hard to trawl (and no fishing allowed in Zone 1 of Gully Marine Protected Area (MPA)) and so are providing some refuge.

Presentation: Variation in Length at Maturity and Distribution of Spawning Fish in NAFO Divisions 3NOPs4VWX as Estimated from the Halibut Longline Survey

Science Lead: N. Shackell
Rapporteur: K. Curran

Summary

Preliminary results, using Observer data, including DFO- Industry Longline survey, of spatial patterns in length at maturity and spawner locations were presented. Only data collected after 2010 were used, due to a change in the methodology used to assign maturity codes. There were 47 Observers in total, but many Observers had only sampled once. Two Observers had extremely anomalous records and operated more in one NAFO region than another, suggesting that the recorded observations might bias the length at maturity estimates. After quality control data from 22 Observers were used. A linear mixed model was fit where Observers were a random effect, landing date was a covariate, and maturity state (mature or immature) was a function of length within sex:NAFO division factor combination. A latitudinal pattern consistent with Bergmann's rule was found (size increases with latitude and colder temperatures).

Currently, the understanding of Halibut follows the Compensatory Juvenile Return Hypothesis (mature animals concentrate and spawn off southern Grand Banks, larvae drift to southwest Nova and migrate back to Grand Banks as they mature). The analysis does not support that notion as immature and mature animals were observed across the entire region. Also observed were 353 fish in spawning condition throughout April through October; some locations overlap with high density areas identified from the RV surveys. As this is contrary to current

understanding of spawning season (spring), we need to verify that the data were not miscoded. In summary, a spatial pattern in Length at 50% Mature was shown that amounted to a 20-25 cm difference from NAFO Division 4X in the south to NAFO Division 3NO in Newfoundland. The length at 50% Maturity for males on the Scotian Shelf is overestimated due to knife-edge selection at sub-legal sizes. This spatial variation has implications for stock assessment as it affects reproductive schedules and fecundity and, ultimately, population growth rate.

Discussion

A meeting participant noted that really high fidelity at age-of-maturity is observed in Pacific Halibut, inquiring if age-at-maturity was explored for Atlantic Halibut (i.e., it is possible that length at maturity varies more than age at maturity) .The Science Lead responded that only length-at-maturity data are available from this dataset, although a new aging program is about to begin and may provide age at maturity data. Another participant asked if histology was considered. The Science Lead responded that Observers do not take gonads for histology.

Presentation: Size at Age by NAFO Division

Science Lead: N. den Heyer
Rapporteur: K. Curran

Summary

Stock productivity and the assessment model are sensitive to changes in growth. In 2003, the Atlantic Halibut Council (AHC) and DFO initiated an Atlantic Halibut otolith aging project. This project developed methods for age determination, used bomb-radiocarbon validation, and had cross validation with the International Pacific Halibut Commission (Armsworthy and Campana 2010). Armsworthy and Campana (2010) selected otoliths from a broad range of fish lengths collected on DFO RV surveys and from commercial trips using otter trawl or longline gear from two periods: historic (1964-1974) and recent (1997, 2001 and 2007). Small differences in growth rate between the two time periods were discovered, but there were large differences in size at age between otter trawl and longline gear. Older studies using different age determination methodologies, suggested that there were differences in growth within the management unit and adjacent management units that were consistent with latitudinal variation. However, Armsworthy and Campana (2010) found only small differences in growth between the Scotian Shelf and Southern Grand Banks.

Here, the aging data from Armsworthy and Campana (2010) was examined at a finer spatial scale, to test for evidence of a latitudinal gradient size at age by NAFO division. This preliminary analysis finds there are significant differences in the size at age of Halibut from northeast to southwest. For females, Halibut from the Grand Banks (3NO) are larger at age than Halibut from the southwest. For males, which are smaller at age, the differences were less pronounced as male size at age is highly variable in this data set. More careful analysis of these data, and the aging of additional otoliths, may provide opportunity to formally test hypothesis about latitudinal variation in growth and size at age. Otoliths are collected on an ongoing basis during the Industry-DFO Halibut Survey (longline gear) and the DFO RV surveys (trawl surveys), with the intention to monitor for changes in growth. Given large changes in abundance of small Halibut since 2007, there may be changes in growth due to density dependent factors. The preliminary analysis suggests that there may also be spatial variation in size at age that, if accounted for, should improve the assessment model.

Discussion

A participant noted that the data permits analysis based on absolute location, but not necessarily when the data are aggregated by NAFO zone. The Science Lead noted that otoliths

can be used to address questions regarding stock structure using microchemistry. A participant observed that the largest fish are found on the southern Grand Banks, but the providence of fish is unknown when they are sampled, so participants should remain open to the idea that movement might be associated with growth rate. A participant noted that, for Pacific Halibut, it is unclear if faster growing fish move more. However, there is an indication in Pacific Halibut that the larger fish do in fact move greater distances relative to smaller fish. The participant suggested using other growth models to further explore the data. Last, another participant suggested the data might be limiting the fit in some NAFO zones (not enough data to have confidence in the fits) and, ideally, there would be enough data from one year for input into the analysis (rather than lumping years). The Science Lead indicated that additional study could be pursued try to address gaps in knowledge. It was generally agreed that variation in growth rate should be explored further, in order to determine if it is related to a latitudinal gradient or temperature, or simply associated with greater movement of faster growing fish.

There was a discussion on length composition data. A participant asked if otolith data existed from the Gulf of St. Lawrence, and it was indicated that data are available for aging purposes.

Presentation: Status of Atlantic Halibut in Canada Versus the United States

Science Lead: N. Shackell
Rapporteur: K. Curran

Summary

Differences in status of Atlantic Halibut in US and Canadian waters exist proximal to the Hague Line. In the US, Halibut was assessed as a Species of Concern in 2004, which is in contrast to abundance in Halibut in Canadian waters that has improved in recent years (the Canadian fishery is now Marine Stewardship Council eco-certified). It is noted that historically Halibut was abundant in coastal and offshore waters of the northeastern US. In the 1940s, there appeared to have been a stock collapse in the US, with a question remaining as to what the cause of this may have been. At present, there are cross border surveys, with more Halibut consistently being caught on the Canadian side of the Hague Line. Efforts to map Halibut habitat preferences have been undertaken to determine if this may have been a cause of Halibut decline in US waters. Results indicate that there still remains an abundance of preferred Halibut habitat in the US northeast area. So why are there no Halibut in US waters? Results suggest that there is the same amount of Atlantic Halibut in the US and southwestern Scotian Shelf on both sides of the Hague Line, so habitat is not a limiting factor (Shackell et al. 2016). The cause of the difference in Halibut abundance remains unanswered but might suggest that stock substructure dynamics not linked to habitat is playing a role (to be explored further with geolocation Bayesian models).

Discussion

A participant asked if habitat suitability changed through time or if it was aggregated across the data set (suggesting changes in temperature are not being captured in the analysis). The Science Lead noted that the data were time aggregated from the 1960s to present, further noting that water temperature has only recently been changing so, given the dataset spans multiple decades, recent changes in water temperature are not believed to be having a large effect in the analysis.

HIGH DENSITY AREAS

Presentation: Species Distribution Model - Northwest Atlantic Habitat Model and Plans: Adding Prey Availability and Fishery Closures as Predictors in the Atlantic Halibut Model

Science Lead: K. French
Rapporteur: K. Curran

Summary

Presented were preliminary/exploratory results of research analyses on species distribution of Atlantic Halibut on the Grand Banks and Scotian Shelf. In years of both high and low abundance, juvenile Halibut appear to be persistently high in two areas on the Scotian Shelf. However, over time, other areas of high abundance appear and disappear (see summary of presentation by S. Boudreau above). Atlantic Halibut seem to inhabit a wide range of environments across the Scotian Shelf (Scott 1982). In exploration of juvenile Halibut choice habitat, the proposed research investigates whether the spatio-temporal variability of the animal's distribution could be - or has been - influenced by environmental and non-environmental variables such as fishing (trawling/fishery closure/ longline effort). The potential to create a field that would represent prey availability was also explored.

Using RV survey presence/absence data, preliminary analysis implemented a species distribution model (MaxEnt) to explore the ability of various environmental variables to define juvenile Halibut habitats. MaxEnt predicts the spatial range of a species by contrasting conditions at presence points with those at known absence points and, with the data available, temperature appeared to be the most confining variable, i.e., temperature variables could explain a significant amount of the spatial variability in the absence/presence of Atlantic Halibut. To investigate the spatio-temporal variability of juvenile Halibut distribution in Atlantic Canada, this research will set a rule to define High Density Areas (HDAs) based on proportional presence of the fish, and explore/compare HDA temporal relations between juvenile Halibut abundance, fishing and prey availability. Early exploratory work gave some indication that current fishery closures may overlap with persistent high density areas, but this work requires further exploration. Furthermore, using R-INLA, spatio-temporal hierarchical bayesian analysis will be performed comparing the previous work of S. Boudreau that was presented at this meeting (see summary of presentation by S. Boudreau above), with a by-region model that includes non-environmental variables as co-variates.

Ultimately, a stronger understanding of the processes that may be behind the spatial variability of juvenile Halibut abundance at a time when populations appear strong, will contribute to effective stock management into the future and the maintenance of this valuable resource/profitable fishery.

Discussion

A participant pointed out that the Laurentian Channel Marine Protected Area of Interest (AOI) boundary appeared to be in the wrong location. It was noted that there is a general need to validate the boundaries of the fishery closure areas that are presented. It was clarified that the analysis included the Gulf of St. Lawrence.

The discussion then focused on prey fields. A participant asked if the prey field would change among areas (e.g. southwestern Scotian Shelf versus Gulf of St. Lawrence), noting that prey data from the Gulf of St. Lawrence is available for inclusion in the model (i.e., stomach content data). A Science Lead asked if there are associated length data and the participant noted that these data are also available. The Science Lead noted that the overall goal is to develop

regional prey fields that account for prey size relative to juvenile Halibut size. A participant then asked what kind of sample size was available for stomach contents and the Science Lead indicated that the dataset is limited. The participant noted that a long time series of stomach contents is available in the US, but noted the results in this more extensive dataset are highly variable, cautioning the use of this data (particularly at seasonal levels). The Science Lead clarified that the stomach content analysis is being used to identify prey species of interest to explore further in more detail. Last, a Science Lead noted that the length composition of RV trawl survey data on the southern Grand Banks differs compared to that from the Scotian Shelf, and this should be considered when developing prey fields for this area; catchability estimates in abundance from RV trawl survey data also require consideration.

DISCUSSION

The Chair reviewed the meeting Terms of Reference with the intent of having an open discussion on all research topics and research directions that would improve our understanding of Halibut stock structure. The Science Leads indicated that the current assessment of Scotian Shelf and southern Grand Banks stock and the one-stock approach was a good starting assumption for the assessment, and that long-term good management would consider impacts of the fishery on the smaller scale (i.e., address local demographic rates and movement between regions). They felt that, to date, Halibut had benefited from specific management measures (juveniles in high density areas on the Scotian Shelf are within full and partial fishery closures, adult refuge in deeper waters, very large fish are not directed for by the fishery), and that continued protection of juveniles would contribute to the long-term health of the stock. As the stock is in the healthy zone, with an increasing harvest, it was noted that this provides opportunity and imperative to think about the stock structure and what additional research might be required to understand the underlying dynamics and the impact of an increasing fishery. The Science Lead also responded that the observed increase in recruitment is widespread across the Northwest Atlantic, even though management differs between the two stocks. This suggests the large-scale recruitment pulse may be partially due to environmental forcing as well as precautionary management decisions.

Now is a good time to pursue scientific research to better understand the population, stock, and fishery, in order to ensure future stock assessments support sustainability of the fishery (participants were reminded that Cod stocks were once of a similar status as the Halibut stock on the Scotian Shelf and southern Grand Banks). There is risk of local depletion/extirpation if fishing is concentrated on particular local subpopulations. High density areas are especially vulnerable to overfishing if connectivity between areas is low and fishing is high. Regardless of whether there is subpopulation structure, to minimize risk of local depletion, areas of persistently high densities should receive some protection in order to sustain the recovered population today and in the future. Last, for reference, a participant familiar with Pacific Halibut noted that the apportionment of Halibut by sub-management area within the stock assessment is not only based on biology and catch but also by historic utilization (management considers historic utilization). It was noted that is, in a sense, a crude spatial management approach that could prevent too much effort on subcomponents, even if that is not the specified purpose of the spatial allocations.

Below, the work presented at the meeting is described as it related to the meeting Terms of Reference (Appendix 2). These are not intended as conclusions but are a summary of ongoing work that was discussed in the context of the framework discussion. Understanding of the stock structure is expected to evolve as more work is carried out.

1. Examine work done to date on Atlantic Halibut stock structure, specifically:

   a. history of the fishery and spatial pattern of landings;

What we know

Spatial-temporal (e.g., seasonal) structure exists in the fishery based on past and present management regimes (e.g., inshore landings are NAFO specified). The concept of stock versus population, however, is very different. While the term "stock" can correspond theoretically to a population, practically, a fraction of a population can be considered a "stock" for management purposes, making the assumption that the stock corresponds closely enough to the population to not compromise the results of the assessment and management.

Population and sub-population structure are never fully known and can change over time (which becomes a long-term science project to deconstruct). One way to approach the problem, in the absence of complete information, is to use a management construct to define sub-stocks. Sub-stocks are the current application of fishing patterns. The exercise then becomes one of using the management construct as a starting point to analyze demographics. At present, the Scotian Shelf and southern Grand Banks Halibut stock assessment and total allowable catch are set at a large scale, with a portion of the quota allocated to a given fleet. Currently, about 60% of allocations are held by the less than 65 foot fixed gear fleets (long-line) in Newfoundland, Nova Scotia and New Brunswick, 20% of allocations are held by the 65-100 ft fixed gear fleet, and 16% are held by the >100 ft (Enterprise Allocation) fleet, which can fish with fixed or mobile gear. A small allocation covers bycatch by the less than 65 foot mobile gear fleets. About half of the quota is fully transferrable among fleets and areas.

What we do not know (gaps)

The historic habitat utilization of Halibut in northeastern US waters is not completely known but has been well documented by historians (see Grasso 2008).

An unknown portion of historical US landings were landed in Canadian waters before the 200 mile limit was put in place.

What research is required

Any scientific analysis should be placed in the context of changing forces acting on the fishery (e.g., regulations, closures, quotas, fleet size, fishing effort, etc.), which could be used to explain spatial-temporal patterns observed in the landings data.

A literature review could address gaps regarding the historic habitat utilization of Halibut in the northeastern US (although a thorough review is available from Grasso (2008), as could external experts, including those at Dalhousie University, Halifax, NS).

Discussion

Meeting participants agreed that the history of the fishery needs to be considered in future analysis (e.g., regulatory changes, closures, effort changes, etc.). The meta-data needs to be accounted for and tracked. Similarly, vessel size and quota allocations should be factored into any spatial analysis, as statistical aggregation of data by regulatory areas often structures scientific thinking, which needs to be considered in stock assessment. Preferably, analysis by regulatory area should be compared to broader analysis with the regulatory areas removed, in order to ensure that scientific thinking is consistent and not driven by biases associated with the regulatory areas. A participant noted that some data are shaped by regulatory areas (e.g., landings), so this needs to be considered where appropriate. In contrast, RV data are not shaped by the regulatory area of the fishery.

It was noted that it would be worth exploring a finer scale allocation of effort as an approach to spread fishing mortality over stock components.

b. **geographical extent of sub-stocks and connectivity between them;**

Current understanding (Broad scale)

The current view of Halibut stock structure is that one population ranges from the southern Grand Banks to Gulf of Maine area.

However, preliminary analysis of the distribution and persistence of RV catches of juvenile Halibut work is providing evidence of finer scale spatial structure.

The INLA modeling exercise suggests there may be two "core areas", both on the Scotian Shelf: one in southwest and one in the Gully. In these two areas, high densities of juvenile Atlantic Halibut are consistently present throughout the RV time series (1970s to present), both in periods of low and high abundance.

In addition to these two "core areas", the model identified numerous (15-20) high density areas throughout the range. High density areas are more ephemeral than "core areas", i.e., are not consistently occupied in both high abundance and low abundance periods. One of these high density areas is off southern Newfoundland. Another high density area may be located in a fishery closure called the "Haddock Box" on the Scotian Shelf.

Connectivity among these high density areas, and between the core areas, appears to change over time.

According to the INLA model presented, in periods of low abundance, the high density areas were small and relatively disconnected from each other despite their close proximity. In periods of high abundance the high density areas were larger and more connected to each other.

Multiple lines of evidence are necessary to evaluate stock structure. Tagging work, spatial patterns, length at maturity, and size at age were all examined across the stock area.

Review of existing tagging studies and some new analysis showed that while some Atlantic Halibut from the Southern Grand Banks and Scotian Shelf stock are recaptured thousands of kilometers from where they are released, the majority of Halibut are recaptured near where they are released, i.e., within the same NAFO zone. While this pattern of movements is consistent with the existence of substructure in the population, more tagging work is required to better understand movement within the population area.

While these observations are consistent with a higher complexity of subpopulation structure than previously assumed, more research is needed in order to identify subpopulations, if any, and estimate the connectivity between them. Most importantly, an understanding is required if our management policies need to respect aspects of connectivity between the subpopulation components, which is not currently considered.

More work is needed to understand seasonal movement patterns and habitat use and spawning behavior. Analysis of PSAT tags recovered in the Gulf of St. Lawrence draws into question the identification of spawning rises on the southern Grand Banks with PSAT tags. However, overall, the traditional tagging and enhanced analysis of movement in the Gulf of St. Lawrence from the PSAT tags supports the current definition of the management units and the seasonal inshore offshore migration to more shallow water in summer, with winter spawning in deep waters.

Current understanding (Nose and Tail)

While no core areas were identified on the Grand Banks, there might be a possible high density area on the tail of the Grand Banks connected to the slope to the east. Many questions remain about the surveys used in the analysis, and a more thorough review of the data would be necessary before anything definitive can be said about this area.

The exploratory work and spatial patterns observed are consistent with connectivity between the Halibut on the tail and other parts of the Grand Banks, although the extent of this small scale connectivity remains unknown.

Current understanding (Georges Bank and Eastern Gulf of Maine)

Historically, Halibut was abundant in coastal and offshore waters of the northeastern US. In the late 1800s, there appeared to have been a stock collapse.

There are ongoing cross border surveys, with more Halibut consistently caught on the Canadian side of the Hague Line. The apparent lack of recovery in US waters remains unanswered.

Both tagging studies and coherent trends in abundance between eastern Gulf of Maine, Bay of Fundy and Southwest Nova suggest connectivity between Halibut on the two sides of the Hague Line.

Recent studies of Halibut habitat availability suggest that preferred habitat (including preferred temperatures) is equally available on the US and Canadian side of the Hague Line, suggesting that stock substructure, specifically the potential lack of resident, locally adapted, spawning subpopulations in US waters since the collapse may explain lack of recovery on the US side.

According to this interpretation, the source for recolonization in US waters would be from Canada. US subpopulations could be re-seeded from Canada through westerly drift of pelagic early life history stages or movement of juveniles and adults.

A research proposal led by Nature Conservancy in the US (with Canadian and US government and university scientists) has been funded to further investigate Atlantic Halibut stock structure through PSAT on Atlantic Halibut released off of Cape Cod. Field work would begin in the spring of 2017.

The bulk of the stock is on the Scotian Shelf and southern Grand Banks, so movement in and out of the management area likely has a small impact on the assessment of the unit. In contrast, movement in and out of the management area could have a larger impact on the assessment of adjacent smaller units, in particular the Gulf of Maine.

What we do not know (gaps)

Although there is some spatial structure to the allocation of quota within the management unit, to date there has been no effort to estimate exploitation rates at a scale smaller. With an expanding fishery there is risk of local depletion /extirpation, particularly if there is smaller scale variation in abundance and/or demographic rates.

There might be a possible Persistent High Density Area of juveniles on the tail of the Grand Banks connected to the slope to the east, although many questions remain about the surveys used in the analysis. It was agreed this requires further investigation before anything definitive can be said about this area.

While these observations are consistent with some subpopulation structure, more research is needed to identify subpopulations, if any, and to estimate the connectivity between them together with any required management changes.

Temporal patterns in high density areas are unknown and should be explored in more detail. Spatial connectivity across international borders is also unknown, with survey information from non-regulated areas (e.g., NAFO Division 3M) yet to be evaluated. Note, however, that connectivity in temporal patterns between eastern Gulf of Maine, Bay of Fundy and Southwest Nova has been documented (Shackell et al. 2016).

In order to evaluate any flow of fish between sub-stocks, there is a need to pursue a much larger tagging program, using conventional, acoustic and/or PIT tags, throughout the Northwest Atlantic. Geo-spatial information from existing PSAT tags could be explored further to determine if there is Halibut movement across subunits and borders. Studies on genetic differences between sub-stocks also could be pursued.

Mixing between the Gulf of Maine and Gulf of St. Lawrence with the Scotian Shelf and southern Grand Banks stocks remains unknown. There may be connectivity across NAFO areas, which can impact all stock assessments (i.e., Gulf of Maine, Gulf of St. Lawrence, and Scotian Shelf and southern Grand Banks), with the potential impact greater for the smaller US stock.

Regardless of population structure, juvenile high density areas are nursery grounds that have benefitted from spatial management measures. On the Scotian Shelf, one of the main high density areas occurs in a Marine Protected Area (i.e., The Gully), another is an area of partial fisheries closures in the general area (i.e., Lobster Fishing Area (LFA) 40 lobster closure and Browns Bank Cod), and a third occurs in a juvenile haddock fishery closure on Western Bank. The apparent appearance and disappearance of other high density areas, including the tail of Grand Bank, should be further investigated. It was suggested that the source of increase in international waters reflects the expansion from Canadian high density areas.

What research is required

Information regarding spatial exploitation rates is required. Any underlying population structure may be revealed through geo-spatial analysis of genetic/genomics information, although how this analysis could be applied to stock assessment requires further consideration (e.g., how would differentiation across the range correspond to spawning areas). It was noted that a review of otolith chemistry might be possible, in order to determine the geographic origin of fish. This could be supplemented by estimating the optimal behaviour of the fishing fleet in relation to the distribution of Halibut, in order to harmonize exploitation rates across sub-stocks. Importantly, the sensitivity of the INLA model requires exploration (perhaps focus on Area 3, as well as add a seasonality component).

Discussion

There was a discussion regarding sub-populations versus sub-stocks, with recognition that these are two different entities. While definitions of stocks can theoretically refer to a population, in practice stocks usually correspond to a management unit, so it was agreed any analysis should be clear in its application to populations or stocks. Although the presentations were made in context of sub-stocks, many participants interpreted the results from a sub-population point of view. A participant suggested the discussion begin with identifying/agreeing to a need to even consider stock sub-structure: does it even matter for assessment purposes? That is, if stock sub-structure does exist, can we say anything meaningful about it at this time. Another meeting participant did not feel the level of knowledge supported the existence of stock sub-structure. There was a discussion of the importance of pursuing this investigation into stock structure, and guidance was sought from participants regarding the type of analysis that could be applied to do so. Another Science Lead noted that there already is a level of understanding of stock structure (e.g., Scotian Shelf and southern Grand Banks versus Gulf of St. Lawrence stocks).

A meeting participant noted that the Prince Edward Island Fishermen Association has been PSAT-tagging Atlantic Halibut in the southern Gulf of St. Lawrence and, in addition, northern Gulf of St. Lawrence data may be available at Mont Joli, Quebec. It was noted that individuals from these groups should be included in future discussions regarding stock structure in the Gulf of St. Lawrence. There was a discussion about the current assumption that the Gulf of St. Lawrence is a separate stock from Scotian Shelf and southern Grand Banks stock. A Science Lead noted there is coherence between NAFO 4Vn and the Gulf of St. Lawrence stock, questioning if fish in NAFO 4Vn are more closely related to the Gulf of St. Lawrence stock compared to the Scotian Shelf and southern Grand Banks stock. This is an important research question that requires more attention before being considered for management purposes. A participant noted that the data from the RV survey only represents location of juveniles. It does not provide any indication of where fish are moving, so the RV data does not provide a basis for stock dynamics. The participant further noted that the RV survey has very different efficiencies in capture depending on the bottom type, emphasizing that limitations of the data must always be kept in mind when used to express analytical results. It was suggested the RV data be compared to patterns in the DFO-Industry survey data.

A participant noted that sub-stock areas may be related to habitat. Another participant also supported this notion, suggesting that biological/habitat differences between high density and low density areas be explored. It was agreed that further work could be undertaken to explore exploitation rates in high density areas to evaluate if they are being disproportionately harvested. A participant noted that persistent areas and high density areas are not the same, recommending that the two concepts be differentiated where referred to (avoid using them synonymously).

There was then a brief discussion on the value of better genetic understanding within the population. Some participants questioned whether any improved understanding of genetics could be used to inform stock assessment. With this in mind, the Science Lead re-iterated that there were no genetic experts at the meeting, and so it would be inappropriate to dismiss the utility of genetics through non-expert opinion. The Science Lead then indicated she would discuss this further with the specialist in genetics who was unable to attend.

It was suggested that evidence of stock sub-structure is clearer at larger scales (i.e., Gulf of St. Lawrence versus the Scotian Shelf and southern Grand Banks, but at smaller, more local scales it is more difficult to interpret (e.g. NAFO Subdivision 4Vn).

Participants noted that biases associated with management boundaries must be accounted for in spatial analysis (particularly tagging data). A participant noted that PSAT tagging on either side of management boundaries (e.g., Hague Line) is worth pursuing, in order to help inform any potential bias associated with the management boundaries. It was agreed that PSAT tags are informative, although the limited number of tags (n=20) requires consideration in its ability to demonstrate/accept connectivity of sub-structures based on such low numbers. A participant familiar with Pacific Halibut agreed that PSAT tags would not provide enough information about population movement for a definitive answer to stock structure. Studies that tag the whole stock at once are better suited to address this type of question. A study that tags Gulf of St. Lawrence and Scotian Shelf and southern Grand Banks as the same time would be ideal, with further consideration to including areas south of the Hague Line. A participant noted that acoustic tags, which are cheaper than PSAT tags, could be used, although for Pacific Halibut the acoustic range was lower than the manufactured standards and not suitable for the hydrophone arrays on that coastline at that time.

There was a discussion regarding the southern extent of the stock south of the Hague Line. Some meeting participants did not feel enough information existed in the Gulf of Maine to

support a direct relationship with the Scotian Shelf and southern Grand Banks stock. A Science Lead felt there was sufficient published evidence to show that the Gulf of Maine and Scotian Shelf were connected (Kanwit 2007, Shackell et al. 2016). It was agreed that US information could be further explored in terms of any potential connection to Canadian stock without it having to be incorporated into the assessment at this time. In terms of the Gulf of St. Lawrence and Scotian Shelf and southern Grand Banks stocks, it might be worth exploring the implications of the respective management regimes on the adjacent stocks, given the much larger relative biomass and fisheries in those areas. The Science Lead noted that while there is some exchange that is not accounted for in the current assessment approach, the assessment currently includes the bulk of Halibut on Scotian Shelf and southern Grand Banks.

There was significant discussion focused on connectivity. It was agreed that preliminary INLA research presented on Persistent High Density Areas for juveniles did not focus on non-regulatory areas. Some participants felt the INLA results could be used to evaluate broad patterns in distribution and connectivity, while other participants expressed discomfort with this, emphasizing that the model was new, not thoroughly tested, and required further exploration of data inputs and model sensitivities. A participant suggested that reference regarding further exploration of connectivity between stock and non-regulated areas could be warranted, but is not supported by preliminary results presented from INLA.

c. **Range of demographic rates within sub-stocks; and**

What we know

Preliminary analyses identified significant spatial variability in length at maturity, age at length, and growth rate. A spatial pattern in length at maturity was observed - preliminary analysis of suggests a 20-25 cm difference in the length at maturity of females from NAFO Division 4X in the south to NAFO Divisions 3NO in Newfoundland.

There was also a spatial pattern observed in size at age and of Halibut from northeast to southwest, with female Halibut from the Grand Banks (3NO) being larger at age and at maturity than Halibut from the northeast. The preliminary analyses also suggest that there may also be spatial variation in growth that, if accounted for, should improve the assessment model.

Given large changes in abundance of small Halibut since 2007, the potential exists for changes in growth due to density dependent factors, as was the case for Pacific Halibut.

More careful analysis of these data, and the aging of additional otoliths, may provide opportunity to formally test hypothesis about latitudinal variation in growth and size at age.

What we do not know (gaps)

Demographic rates may be related to genetics, density, and/or food availability, and comparison of demographic rates among areas is complicated by the fact that the extent of movement between areas is unknown.

What research is required

Revisit the aging of otoliths to update the growth model and to monitor for change in growth over time. Research on maturity of Halibut using histology should also be pursued.

Discussion

The Science Lead indicated that it might be premature to draw any conclusion regarding movement between the two large management areas, as it was not discussed at the meeting. This point was supported by meeting participants. It was agreed that caution be exercised in how movement (or not) is characterized; particularly, given that the number of tagged fish remains relatively small. It was noted that the bulk of the stock biomass is on the Scotian Shelf

and southern Grand Banks, so movement in/out of the area likely has only small impact on the assessment of the management unit. In contrast, movement could have a large impact on the assessment of adjacent smaller units, in particular the Gulf of Maine and to a lesser extent the Gulf of St. Lawrence.

d. implications for assessment model(s)

A better understanding of stock structure is important for better management between countries, but also is required to support sustainable management domestically.

There is opportunity to learn from Northwest Atlantic groundfish fishery collapses in the early-1990s and incorporate that knowledge into future Halibut stock assessments.

Two related themes that emerge from the literature are relevant here:

- the spatial scale of a stock management unit is often larger than the spatial scale of genetic and/or life history differences among potential subpopulations (Bradbury et al. 2008, Cadrin et al. 2013, Cadrin et al. 2010, Kuparinen et al. 2016, Roney et al. 2016, Smedbol and Wroblewski 2002), and
- even in the absence of genetic/life history differences, the spatial distribution of fish and fishing is never uniform across a region and local concentrations can be fished out (spatial erosion (Ames and Lichter 2013, Bartolino et al. 2012, Ciannelli et al. 2013, Frank and Brickman 2000, Kerr et al. 2010, Maury and Gascuel 2001, and Shackell et al. 2005)).

Given the evidence in other species/systems, can it be addressed as to whether there is spatial variation in demographic rates in Halibut, and whether there is a requirement to safeguard against spatial erosion by an appropriate spatial allocation of fishing effort?

Spatial variability in demographic rates (e.g., growth rate and age/ length at maturity) across the stock area should be taken into account in assessments to more accurately model stock dynamics.

The stock is in a healthy state; it is a good time to pursue scientific research to better understand the population, stock, and fishery, in order prevent loss of stock components and support sustainability of the fishery.

Although there is some spatial structure to the allocation of quota within the management unit, to date there has been no effort to estimate exploitation rates at a scale smaller. With an expanding fishery, there is risk of local depletion /extirpation, particularly if there is smaller scale variation in abundance and/or demographic rates. High density areas are especially vulnerable to overfishing if connectivity between areas is low and fishing is high.

What research is required

If stock sub-structure exists, the implications for harvest policy, specifically in context of the multi-species groundfish licences, require consideration.

Discussion

There was no agreement that population sub-structure existed. A Science Lead noted that sub-structure, if it exists, might inform future assessments and harvest advice; for example, ensuring that sub-subpopulations are not disproportionately fished. At present, these types of science questions are not being explored, and it is unknown if the data exists to monitor fishing mortality at a smaller spatial scale than the management unit. It was noted that if sub-structure exists, the implications for the assessment model would depend on the level of connectivity between the sub units. A Management Strategy Evaluation (MSE) management approach could be explored if sub-structure is shown to exist (review of the harvest policy being used). A participant noted

that consideration could be given to the Gulf of St. Lawrence, although it was noted that the meeting Terms of Reference were limited to discussion related to the Scotian Shelf and southern Grand Banks Atlantic Halibut stock.

A participant familiar with the assessment of Pacific Halibut commented that there can also be risks associated with assessment and management at smaller spatial scales. If the information available is not sufficient to estimate migration and exploitation rates at these smaller scales, or to detect and respond to changes in those rates, there is a risk of overexploitation of substocks as a result. If the designation of those smaller components is wrong, then there is still the risk of overexploitation. Only a massive and expensive tagging program can provide reasonable migration estimates.

2. **Examine the habitat in high density areas (prey, sediment type, temperature, and depth) to explore what it is about these areas that make them so productive for Atlantic Halibut.**

What we know

Preliminary analysis identified two areas of persistently high juvenile abundance (i.e., southwest Scotian Shelf and the Gully Canyon) in July, which is consistent with historical catch rates. Juvenile abundance, however, does not appear uniform over space or time.

What we do not know (gaps)

The timing of surveys is important and a re-analysis by each large region (including Gulf of St. Lawrence and Newfoundland) is needed. It remains unknown as to why juveniles are found in certain habitats.

What research is required

Potential factors (e.g., fishing closures and prey availability) correlated with the emergence and reduction of juvenile Halibut high density areas over time require investigation.

Discussion

There was a discussion regarding the mapping of high density areas of juvenile Halibut. It was generally felt that the findings presented were preliminary and required more detailed analysis. In addition, more thorough discussion on a definition and criteria of high density areas, as well as a more thorough review of the analytical tools used to identify them, is required.

3. **If, upon examination, the Scotian Shelf and Southern Grand Bank stock appears to have significant substructure, there will be an evaluation of how stock structure could/should be taken into account in assessment and management (i.e., consider whether the one-stock assumption matters to the health of the population and explore methods of how multiple, connected populations could be managed safely). These questions on stock structure will not be definitive in the short-term; therefore, the discussion will consider how to manage the stock with incomplete information.**

What we know

See also 1d above.

Preliminary analyses demonstrate spatial variation in growth rate and length at maturity by NAFO region. Temporal changes in abundance throughout the Northwest Atlantic are coherent across large areas, suggesting that Halibut are responding to large-scale forcing and/or connectivity. Exploratory research has estimated connectivity to be approximately 400 km, although this is considered to be an average across the entire range and does not relate to

small scale connectivity. Last, exploratory work and spatial patterns are consistent with connectivity between the Halibut on the tail and other parts of the Grand Banks.

What we do not know (gaps)

The level of small scale connectivity remains unknown (e.g. across tail of Grand Banks in NAFO Division 3M).

What research is required

Sub-structure of the stock needs to be examined at a scale smaller than the Scotian Shelf and southern Grand Banks, if possible. A large-scale stock assessment that incorporates spatial variation in longline Halibut survey index and fishing could be explored.

Discussion

The Science Lead noted that sub-structure of the stock exists from a management context and awareness of this is insightful in terms of further understanding of the assessment (i.e., one total allowable catch being applied to different fleets). A participant noted that the concept of stock versus population requires clarification in future presentation of results. It was noted that population is a biological construct and stock can refer to a management unit that may or may not represent a biological unit, and providing clarification of which construct is used in the underlying analysis is helpful as the two are often assumed to be synonymous.

4. **Recommend how future research should be focused to further our understanding of Atlantic Halibut stock structure and population dynamics more broadly (provide a prioritized list).**

Method	Knowledge/Status	Next steps	Who? When?
Spatial Structure			
SpatioTemporal Model	3NOPs4VWX5Zc assumed one stock, distinct	focus on 3NOPs	TBD
Local Demographics			
High density areas demographics + sub stock	incomplete	revisit growth, maturity, landings, recruitment by sub stocks	See below
Population Structure			
SNIPS	Mitochondrial DNA	Develop proposal, find funding, identify likely spawning areas	Ian Bradbury
Otolith microchemistry	4Vn/Gulf: differences in the ocean currents and possibly signatures	TBD	TBD
Movement, Dispersal, and Habitat Use			
Traditional tagging	Data show large-scale movements but most predominantly stay near by; never looked formally at distribution of fishing effort	-investigate heterogeneity in movement (resident, dispersal, seasonal migration) -estimate transitions/connectivity between core areas	Nell & others
Larger scale, traditional, PIT tag	Start with simulation, analysis, planning, evaluate design rewards,		

Method	Knowledge/Status	Next steps	Who? When?
	types of tags		
PSAT	Evidence of seasonal movement for mature individuals.	Analysis seasonal movement for smaller (81-118 cm) Halibut; Investigate seasonal shifts in distribution and availability to fishery; geolocation. Can geolocation model be used on Scotian Shelf and southern Grand Banks?	Collaboration with MUN (Dominique Robert), The Nature Conservancy (Chris McGuire) Graduate student funding in Newfoundland, RDC/NSERC,
Acoustic tags		Investigate connectivity/movement of Halibut in 4Vn (new juvenile Halibut high density area– where do they go may tell us where they came from?)	MPA/OTN/Industry collaboration Glider technology and collaboration in US
MSE Approach			
Population modelling	Statistical catch at length model for stock assessment; projection model for assessment of risk of harvest strategies	Explore alternative assessment models and sensitivity analysis for spatial variation in fishing exploitation and variation in growth, maturity.	TBD

CONCLUSIONS

The Scotian Shelf and southern Grand Banks Atlantic Halibut stock is in the healthy zone. This discussion provided opportunity to explore additional research options that could be pursued in support of the long-term viability of the stock. It was noted that a discussion of this nature is consistent with a proactive and precautionary approach to management. In general, meeting participants, which included a group of international government and academic scientists, managers, and industry, welcomed the discussion. Sincere efforts were made to acknowledge and address all comments and concerns raised by meeting participants provided they were appropriate and within the confines of acceptable peer review practice. This Proceedings document constitutes a record of meeting discussions, recommendations, and conclusions, and any statements within should not be attributed as being consensus-based. A Science Advisory Report was not a product of the meeting.

REFERENCES CITED

Ames, E.P., and Lichter, J. 2013. Gadids and Alewives: Structure Within Complexity in the Gulf of Maine. Elsevier B.V., Fish. Res. 141: 70–78.

Armsworthy, S.L., and S.E. Campana. 2010. Age Determination, Bomb-radiocarbon Validation and Growth of Atlantic Halibut (*Hippoglossus hippoglossus*) from the Northwest Atlantic. Environ. Biol. Fish. 89: 279-295.

Bartolino, V., L. Ciannelli, P. Spencer, T.K. Wilderbuer, and K. Chan. 2012. Scale-dependent Detection of the Effects of Harvesting a Marine Fish Population. Mar. Ecol. Prog. Ser. 444: 251–261.

Bradbury, I.R., B.J. Laurel, D. Robichaud, G.A. Rose, P.V.R. Snelgrove, R.S. Gregory, D. Cote, and M.J.S. Windle. 2008. Discrete Spatial Dynamics in a Marine Broadcast Spawner: Re-evaluating Scales of Connectivity and Habitat Associations in Atlantic Cod (*Gadus morhua* L.) in Coastal Newfoundland. Fish. Res. 91: 299–309.

Cadrin, S.X., M. Bernreuther, A.K. Danielsdóttir, E. Hjörleifsson, T. Johansen, L. Kerr, K. Kristinsson, S. Mariani, K. Nedreaas, C. Pampoulie, B. Planque, J. Reinert, F. Saborido-Rey, T. Sigurðsson, and C. Stransky. 2010. Population Structure of Beaked Redfish, *Sebastes mentella*: Evidence of Divergence Associated with Different Habitats. ICES J. Mar. Sci. 67: 1617–1630.

Cadrin, S.X., L.A. Kerr, and S.E. Mariani (Eds). 2013. Stock Identification Methods: Applications in Fishery Science (Second Edition) Elsevier Academic Press (2013).

Carson, S., and J.M. Mills Flemming. 2014. Seal Encounters at Sea: A Contemporary Spatial Approach Using R-INLA. Ecol. Model. 291: 175-181.

Ciannelli, L., J.A.D. Fisher, M. Skern-mauritzen, M.E. Hunsicker, M. Hidalgo, K.T. Frank, and K.M. Bailey. 2013. Theory, Consequences and Evidence of Eroding Population Spatial Structure in Harvested Marine Fishes : A Review. Mar. Ecol. Prog. Ser. 480: 227–243.

Cox, S.P., A. Benson, and C.E. den Heyer. 2016. Framework Stock Assessment for Atlantic Halibut on the Scotian Shelf and Southern Grand Banks. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/001. vi + 54 p

den Heyer, C.E, A. Armsworthy, S. Wilson, G. Wilson, L. Bajona, S. Bond, and M.K. Trzcinski. 2012. Atlantic Halibut All-sizes Tagging Program Summary Report for 2006 to 2011. Can. Tech. Rep. Fish. Aquat. Sci. 2992: vii+34 p.

DFO. 2015a. 2014 Assessment of Atlantic Halibut on the Scotian Shelf and Southern Grand Banks (NAFO Divisions 3NOPs4VWX5Zc). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2015/012.

DFO. 2015b. 2014 Assessment of Atlantic Halibut on the Scotian Shelf and Southern Grand Banks (NAFO Divisions 3NOPs4VWX5Zc). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2015/012.

DFO. 2015c. Stock Assessment of Atlantic Halibut of the Gulf of St. Lawrence (NAFO Divisions 4RST) for 2013 and 2014. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2015/023.

Frank, K.T., and D. Brickman. 2000. Allee Effects and Compensatory Population Dynamics Within a Stock Complex. Can. J. Fish. Aquat. Sci. 57: 513–517.

Frank, K.T., B. Petrie, and N.L. Shackell. 2007. The Ups and Downs of Trophic Control in Continental Shelf Ecosystems. Trends Ecol. Evol. 22: 236-242.

Frank, K.T., B. Petrie, J.S. Choi, and W.C. Leggett. 2005. Trophic Cascades in a Formerly Cod-dominated Ecosystem. Science, 308: 1621-1623.

Grasso, G.M. 2008. What Appeared Limitless Plenty: The Rise and Fall of the Nineteenth-Century Atlantic Halibut Fishery. Environ. Hist. 13:66-91.

Jensen, A.G., and J.P. Wise. 1961. Movement of Tagged Halibut off New England – II. Trans. Am. Fish. Soc. 90: 489-490.

Kanwit, J.K. 2007. Tagging Results from the 2000–2004 Federal Experimental Fishery for Atlantic Halibut (*Hippoglossus hippoglossus*) in the Eastern Gulf of Maine. J. Northw. Atl. Fish. Sci. 38: 37–42.

Kerr, L.A., S.X. Cadrin, and D.H. Secor. 2010. Simulation Modelling as a Tool for Examining the Consequences of Spatial Structure and Connectivity on Local and Regional Population Dynamics. ICES J. Mar. Sci. 67: 1631–1639.

Kohler, A.C. 1964. Movements of Halibut on the Nova Socitan and Grand Banks. J. Fish. Res. Bd. Canada 24: 53-56.

Kuparinen, A., N.E. Roney, R.A. Oomen, J.A. Hutchings, and E.M. Olsen. 2016. Small-scale Life-history Variability Suggests Potential for Spatial Mismatches in Atlantic Cod Management Units. ICES J. Mar. Sci. 73: 286–292.

Maury, O., and D. Gascuel. 2001. 'Local Overfishing' and Fishing Tactics: Theoretical Considerations and Applied Consequences in Stock Assessment Studied. Aquat. Living Resour. 14: 203–210.

McCracken, F.D. 1958. On the Biology and Fishery of the Canadian Atlantic Halibut, *Hippoglossus hippoglossus* L. J. Fish. Res. Bd. Canada 15(6): 1269-1311.

Roney, N.E., J.A. Hutchings, E.M. Olsen, H. Knutsen, J. Albretsen, and A. Kuparinen. 2016. Fine-scale Life-history Structure in a Highly Mobile Marine Fish. Evol. Ecol. 95–109.

Scott, J.S. 1982. Depth, Temperature and Salinity Preferences of Common Fishes of the Scotian Shelf. J. Northwest Atl. Fish. Sci. 3: 29-39.

Shackell, N.L., K.T. Frank, and D.W. Brickman. 2005. Range Contraction May not Always Predict Core Areas: An Example from Marine Fish. Ecol. Appl. 15: 1440–1449.

Shackell, N.L., K.T. Frank, J.A. Nye, and C.E. den Heyer. 2016. A Transboundary Dilemma: Dichotomous Designations of Atlantic Halibut Status in the Northwest Atlantic. ICES J. Mar. Sci. 73(7). (doi:10.1093/icesjms/fsw042)

Smedbol, R.K., and J.S. Wroblewski. 2002. Metapopulation Theory and Northern Cod Population Structure: Interdependency of Subpopulations in Recovery of a Groundfish Population. Fish. Res. 55: 161–174.

Stobo, W.T., and G.M. Fowler. 2006. Canadian Tagging of Commercial Groundfish and Small Pelagic Fish in the Vicinity of the Scotian Shelf and Gulf of St. Lawrence, 1953-1985. Can. Tech. Rep. Fish. Aquat. Sci. 2669: xii+137p.

Stobo, W., J.D. Neilson, and P. Simpson. 1988. Movements of Atlantic Halibut (*Hippoglossus hippoglossus*) in the Canadian North Atlantic: Inference Regarding Life History. Can. J. Fish. Aquat. Sci. 45:484-491.

Trzcinski, M.K., and W.D. Bowen. 2016. The Recovery of Atlantic Halibut: A Large, Long-lived, and Exploited Marine Predator. ICES J. Mar. Sci. 73(7). (doi: 10.1093/icesjms/fsv266)

Trzcinski, M.K., S.L. Armsworhty, S. Wilson, R.K. Mohn, and S.E. Campana. 2011. A Framework for the Assessment of the Scotian Shelf and Southern Grand Banks Atlantic Halibut Stock. DFO Can. Sci. Avis. Res. Doc. 2011/002. 118pp.

APPENDICES

APPENDIX 1: LIST OF MEETING PARTICIPANTS

Day 1	Day 2	Day 3	Name/Nom	Affiliation
x	x		Arnold, Shannon	Ecology Action Centre (EAC)
x	x		Boudreau, Stephanie	Oceana Canada
x	x	x	Carruthers, Erin	Fish, Food and Allied Workers
x	x	x	Courchesne, Sandra	DFO NCR / Fisheries Resources Management
x	x	x	Cull, Felicia	DFO National / International Affairs
x	x	x	Curran, Kristian	DFO Maritimes / Centre for Science Advice
x			Dedrick, Gerry	Atlantic Halibut Council / Shelburne Co. Quota Group
x	x	x	den Heyer, Nell	DFO Maritimes / Population Ecology Division (BIO)
x	x	x	Desgagnes, Mathieu	DFO Québec / Science (IML)
x	x	x	Fisher, Jonathan	Memorial University of Newfoundland (MUN)
x	x	x	Ford, Jennifer	DFO Maritimes / Resource Management
x			Frank, Ken	DFO Maritimes / Oceans & Ecosystem Science
x	x	x	French, Kiyomi	DFO Maritimes / Oceans & Ecosystem Science
x	x	x	Hennen, Daniel	NOAA / NMFS
x			Kerr, Lisa*	Gulf of Maine Research Institute
x	x	x	Krohn, Martha	DFO NCR / Fisheries Population Science
x	x	x	Lang, Shelley	DFO Maritimes / Population Ecology Division (BIO)
x	x		Leaman, Bruce	International Pacific Halibut Commission (IPHC)
x	x		McGuire, Christopher	The Nature Conservancy
x			Mohn, Robert	DFO Maritimes Science (retired)
x	x	x	Murphy, Hannah	Memorial University of Newfoundland (MUN)
x	x	x	Robert, Dominique	Memorial University of Newfoundland (MUN)
x	x	x	Shackell, Nancy	DFO Maritimes / Oceans and Ecosystem Science
x			Stortini, Christine	DFO Maritimes / Oceans and Ecosystem Science
x	x	x	Vascotto, Kris	Atlantic Halibut Council
	x	x	Zemeckis, Douglas*	University of Massachusetts, Dartmouth

* Attended meeting via WebEx.

APPENDIX 2: MEETING TERMS OF REFERENCE

Regional Framework Discussion on Stock Substructure of Northwest Atlantic Fisheries Organization (NAFO) Division 3NOPs4VWX5Zc Atlantic Halibut (Scotian Shelf and Southern Grand Banks)

Regional Framework Discussion – Maritimes Region

9-11 March 2016
Dartmouth, Nova Scotia

Chairperson: Martha Krohn

TERMS OF REFERENCE

Context

Atlantic Halibut (*Hippoglossus hippoglossus*) is a large and long-lived flatfish. It ranges widely in the waters off of Atlantic Canada. The management unit, the Northwest Atlantic Fisheries Organization (NAFO) Divisions 3NOPs4VWX5Zc (Scotian Shelf and Southern Grand Banks), is based largely on tagging results, which indicate that Atlantic Halibut moves extensively throughout the Canadian North Atlantic. A new assessment framework for 3NOPs4VWX5Zc Atlantic Halibut was accepted in November, 2014 (DFO 2015a). The last stock assessment was conducted December 8-9, 2014 (DFO 2015b). A stock update was completed December 3, 2015. The stock status of 3NOPs4VWX5Zc Atlantic Halibut is in the healthy zone. Recovery of the stock has allowed for increased access by Canadian domestic and international fishing fleets. Continued sustainable exploitation of this resource would benefit from a collaborative approach between the three coastal states that have a primary interest in the stock: Canada; United States; and France.

Recent research has identified core areas of juvenile Halibut that may be indicative of 3NOPs4VWX5Zc Atlantic Halibut stock substructure on the Scotian Shelf and Southern Grand Banks. A better understanding of Halibut substructure and connectivity between core areas would provide a basis for sustainable management. Multiple lines of evidence are necessary to evaluate stock structure and the appropriate management strategies in the face of this new data synthesis. This science framework discussion will support the development of a Halibut research program and a common understanding of stock structure among the three coastal states. This common understanding will inform the development of management strategies that, if deemed appropriate, will take stock structure into account to achieve sustainable exploitation.

Objectives

The objectives of this science framework discussion are to:

1. Examine work done to date on Atlantic Halibut stock structure, specifically:
    - history of the fishery and spatial pattern of landings;
    - geographical extent of sub-stocks;
    - connectivity between sub-stocks;
    - range of demographic rates within sub-stocks; and
    - implications for assessment model(s).
2. Examine the habitat in core areas (prey, sediment type, temperature, and depth) to explore what it is about these areas that make them so productive for Atlantic Halibut.
3. If, upon examination, the Scotian Shelf and Southern Grand Banks stock appears to have significant substructure, there will be an evaluation of how stock structure could/should be taken into account in assessment and management (i.e., consider whether the one-stock

assumption matters to the health of the population and explore methods of how multiple, connected populations could be managed safely). These questions on stock structure will not be definitive in the short-term; therefore, the discussion will consider how to manage the stock with incomplete information.

4. Recommend how future research should be focused to further our understanding of Atlantic Halibut stock structure and population dynamics more broadly.

The first three objectives above (1-3) will be addressed to the extent possible based on work completed to date, including all available evidence in the context of connectivity among core areas and how connectivity varies with total population size. Connectivity in other stocks has been shown to deteriorate as populations decline, and the distance between patches increases. In this context, approaches to ensure all high density core areas are sustained will be considered. Remaining gaps in our understanding will be identified and directions for future research to fill these gaps will be recommended for both the short- and long-terms.

Expected Publications

- Proceedings
- Research Document(s)

Participation

- DFO Science
- DFO Resource Management
- International (United States and France)

References

DFO. 2015a. Proceedings of the Regional Framework and Assessment of the Scotian Shelf and Southern Grand Bankss Atlantic Halibut (*Hippoglossus hippoglossus*) in NAFO Divisions 3NOPs4VWX5Zc; November 3-6, 2014, and December 8-9, 2014. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2015/040.

DFO. 2015b. 2014 Assessment of Atlantic Halibut on the Scotian Shelf and Southern Grand Bankss (NAFO Divisions 3NOPs4VWX5Zc). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2015/012.

APPENDIX 3: MEETING AGENDA

Regional Framework Discussion on Stock Substructure of Northwest Atlantic Fisheries Organization (NAFO) Division 3NOPs4VWX5Zc Atlantic Halibut (Scotian Shelf and Southern Grand Banks)

Regional Framework Discussion – Maritimes Region

9-11 March 2016
Dartmouth, Nova Scotia

Chairperson: Martha Krohn

DRAFT AGENDA

DAY 1 (Wednesday, March 9, 2016): The overarching goal of this workshop is to advance our understanding of stock structure of the Atlantic Halibut, how local concentrations are connected, and improve management of a key transboundary stock. Please note, some of the presentations marked " prelim"may change by March 9th.

Time	Topic	Leads
09:00 – 09:20	Welcome / Round table introductions (context for participation, role, research interests, affiliation) /Agenda Revisions	Martha Krohn, DFO Headquarters
09:20 – 9 :40	Current View of Stock structure, how we came to question that, and workshop expectations	Nancy Shackell, DFO Maritimes
09:40 – 10:10	History and recovery of Atlantic Halibut: a large, long-lived, and exploited groundfish	Nell den Heyer, DFO Maritimes
10:10 – 10:40	From the other coast: Pacific Halibut from California to the Bering Sea: Biology and Management Don't Mix	Bruce Leaman, IPHC
10:40 – 11:00	*Break (coffee/tea provided)*	
11:10 – 11:20	Atlantic Industry Perspective: Who we are, and what we have learned from Longline survey	Kris Vascatto, Executive Director, GEAC
DISTRIBUTION and MOVEMENT: Review of Tagging, PSAT in GSL		
11:20 – 11:40	Recovery of the Gulf of St. Lawrence Atlantic Halibut fishery to a 50 year high: data needs and collaborative research opportunities	Hannah M. Murphy MIN, MUN Newfoundland
11:40 – 12:00	Pop-up satellite archival tag (PSAT) temporal data resolution affects interpretations of Atlantic Halibut spawning behaviour, vertical habitat use and movement	Jonathan A. D. Fisher, MIN, MUN Newfoundland
12:00-13:00	*Lunch (not provided)*	
13:00–13:10	Review/Comments from the Chair	Martha Krohn, DFO Headquarters
13:10-13:30	Habitat associations, seasonal movements and population structure of Atlantic Halibut in the Gulf of St. Lawrence inferred from pop-up satellite archival tags	Dominique Robert MIN, Newfoundland
13:30-13:50	USA Perspective and PSAT Plans for Halibut on Georges Banks and Gulf of Maine	Daniel Hennen, NOAA,NEFSC; Chris McGuire Nature

Time	Topic	Leads
		Conservancy, Boston USA
Evidence For and Against Currently Assumed Stock Structure		
13:50 – 14:30	Areas of persistent high juvenile Atlantic Halibut abundance through decades of fisheries exploitation in the Northwest Atlantic	Stephanie Boudreau, Oceana International, Halifax NS
14:30– 15:00	History of tagging, (and anecdotal evidence of where spawning occurs)	Nell den Heyer, DFO Maritimes
15:00 – 15:15	*Break (not provided)*	
Evidence For and Against Currently Assumed Stock Structure		
15:15– 15:40	PRELIM: Variation in Length at Maturity and distribution of spawning fish in NAFO divisions 3NOPs4VWX as estimated from Halibut Longline Survey	Nancy Shackell, DFO Maritimes
15:40 – 16:00	PRELIM Variation in Age at Maturity	Nell den Heyer, DFO Maritimes
16:00 - 17:00	DISCUSSION: Summary of Day; Outstanding questions	Martha Krohn, DFO Headquarters

DAY 2 (Thursday, March 10, 2016): The overarching goal of this workshop is to advance our understanding of stock structure of the Atlantic Halibut, how local concentrations are connected, and improve management of a key transboundary stock.

Time	Topic	Leads
09:00 – 09:30	Recap of previous day and discussion	Martha Krohn, DFO Headquarters
Building on Boudreau's Work on Persistent High Density Areas: Next Steps		
09:30 – 10:20	PRELIM Species Distribution Model: NW Atlantic habitat model and plans: adding Prey availability, Fishery closures as predictors in	Kiyomi French. DFO Maritimes
10:20 – 10:00	*Break (coffee/tea provided)*	
11:00 – 11:15	PRELIM Species Distribution Model Plans: adding Prey availability, Fishery closures as predictors in NW Atlantic habitat model	Kiyomi French. DFO Maritimes
11:30– 12:00	Now that it's recovered- moving towards an Ecosystem-based Management Plan for Halibut: What do we need to know to verify stock structure ,vital rates, movement, ecology	Nell den Heyer and Nancy Shackell, DFO Maritimes
12:00 - 13:00	*Lunch (not provided)*	
13:00 – 13:20	Review/Comments from the Chair: Setting up Discussions	Martha Krohn, DFO Headquarters

Time	Topic	Leads
13:20 – 14:15	DISCUSSION: Consider whether the one-stock assumption matters and explore methods of how multiple, connected populations could be managed safely. These questions on stock structure will not be definitive in the short-term; therefore, the discussion will consider how to manage the stock with incomplete information.	Martha Krohn, Nancy Shackell and Nell den Heyer, DFO
14:15– 15:00	DISCUSSION: Consider how our current understanding of stock structure could inform the development of management strategies that, if deemed appropriate, will take stock structure into account to achieve sustainable exploitation.	Martha Krohn, Nancy Shackell and Nell den Heyer, DFO
15:00 – 15:15	*Break (not provided)*	
15:15 – 17:00	DISCUSSION: Recommend how future research should be focused to further our understanding of Atlantic Halibut stock structure and population dynamics more broadly.	Martha Krohn, Nancy Shackell and Nell den Heyer, DFO

DAY 3 (Friday, March 11, 2016): The overarching goal of this workshop is to advance our understanding of stock structure of the Atlantic Halibut, how local concentrations are connected, and improve management of a key transboundary stock.

Time	Topic	Leads
09:00 – 09:20	Recap of previous day and discussion	Martha Krohn, DFO Headquarters
09:20 – 10:00	DRAFT Proceedings: Atlantic Halibut Research Game Plan (using Nell's plan as starting point)	Martha Krohn, Nancy Shackell and Nell den Heyer, DFO
10:30 – 11:00	*Break (coffee/tea provided)*	
11:00 – 11:30	DRAFT Proceedings: Regional Framework Discussion on Stock Substructure of NAFO 3NOPs4VWX5Zc Atlantic Halibut	Martha Krohn, Nancy Shackell and Nell den Heyer, DFO
11:30	*End –Thank you All*	